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EVALUATION AND DEMONSTRATION OF THE CAPILLARY SUCTION SLUDGE DEWATERING DEVICE

T. E. Lippert, et al

Westinghouse Electric Corporation

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By

T. E. Lippert
M. C. Skriba
Westinghouse Electric Corporation
Research and Development Center
Pittsburgh, Pennsylvania 15235

Program Element 1B2043

Project Officer

J. E. Smith, Jr.
Advanced Waste Treatment Research Laboratory
National Environmental Research Center
Cincinnati, Ohio 45268

NATIONAL ENVIRONMENTAL RESEARCH CENTER
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
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The National Environmental Research Center -- Cincinnati has reviewed this report and approved its publication. Approval does not signify that the contents necessarily reflect the views and policies of the U. S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

FOREWORD

Man and his environment must be protected from the adverse effects of pesticides, radiation, noise and other forms of pollution, and the unwise management of solid waste. Efforts to protect the environment require a focus that recognizes the interplay between the components of our physical environment--air, water, and land. The National Environmental Research Centers provide this multidisciplinary focus through programs engaged in

- studies on the effects of environmental contaminants on man and the biosphere, and
- a search for ways to prevent contamination and to recycle valuable resources.

The research reported here was performed for the Ultimate Disposal Section of the Advanced Waste Treatment Research Laboratory to develop and demonstrate a new method of activated sludge (concentrated pollutant stream) dewatering. Since sludge handling and disposal represents a significant part of the total wastewater treatment cost, a new dewatering technique which promises higher cake solids at higher loading rates and a cleaner filtrate at reduced cost is very welcome.

A. W. Breidenbach, Ph.D.
Director
National Environmental
Research Center, Cincinnati

ABSTRACT

A device for dewatering waste activated sludge that uses the capillary suction in a porous belt has been demonstrated on a pilot scale test unit. The system uses capillary action to initially dewater the sludge and form a thin sludge cake which is then mechanically compressed in a final step to obtain a still dryer cake. Both dewatering steps are incorporated into a single system endless belt design. Sludge feed capacities from 2 to 4.5 lbs/hr ft^2 (10 to 22 Kgs/hr m^2) have been demonstrated with the cake solids at discharge ranging from 15 to 18 percent. These results were obtained with a conditioned waste activated sludge at a coagulant cost of approximately $4.00/ton ($4.40/metric ton). The device has also been tested on an anaerobically digested and a mixed primary-activated sludge.

This report was submitted in fulfillment of Research Contract 68-01-0094 under the sponsorship of the Environmental Protection Agency, Advanced Waste Treatment Research Laboratory.

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The support of the project by the Environmental Protection Agency and the many useful contributions made by Dr. J. E. Smith, Jr., Project Officer, is greatly appreciated.

The bulk of the experimental testing was conducted at the Westinghouse test facility located at the Long Road Sewage Treatment Plant, Penn Hills, Pittsburgh, Pennsylvania, under the capable guidance of Mr. R. F. Watson. The cooperation of the sewage plant personnel, Mr. Ronald Young, Mr. Ernest O'Malley, and Mr. Matthew Drop and the cooperation of the Penn Hills Municipal Authorities is greatly acknowledged.

Sampling and analysis throughout the test program were performed by Mr. M. J. Testa, Mr. J. W. Parks, and Mr. C. G. Slater. The typing of the manuscript was done by Miss Darlene Kuszyk.

SECTION I

CONCLUSIONS AND RECOMMENDATIONS

A device for dewatering waste activated sludge that uses the capillary suction in a porous belt has been demonstrated on a pilot scale test unit. The device was also tested on an anaerobically digested and a mixed primary/activated sludge. Feed capacities from 2 to 4.5 lbs d.s./hr ft^2 (10 to 22 Kgs/hr m^2) were achieved with the cake solids at discharge ranging from 15 to 18 percent for activated sludge. Machine capacities more than twice these values may be possible. It was found that the device can be operated without coagulant addition at a penalty to solids capture. With chemical addition of the polyelectrolyte at 10 lbs/ton (5 Kgs/metric tons) or about $4.00/ton ($4.40/metric ton) a cake solids capture of 95 percent can be obtained when the machine is operated at 2.0 lbs/hr ft^2 (10 Kg/hr m^2). Operating at higher machine capacities, i.e., 4.0 lbs/hr ft^2 and higher, it appears that the ferric chloride conditioner yields more economical system operation. Overall machine operation was found to depend on chemical addition, sludge solids loading and screen mesh size.

This study has led to the development of a sound engineering understanding of the operation of this device including the advancement and development of specific design curves applicable to the particular waste activated sludge used. It is recommended that supporting data from other plants on waste activated sludge be developed to verify these results. Furthermore, additional data and analysis is required to optimize system capacity with respect to both solids loading and chemical addition. Present data indicates that such an analysis could lead to developing machine capacities as high as 20 lbs/hr ft^2 (100 Kg/hr m^2). Additional screen evaluations are needed to establish if screen type and design significantly effect the capillary dewatering rate and sludge cake detachment (i.e., preferential adherence to the compression roller as opposed to staying attached to the screen). Operation of a full scale field unit is required in order to establish realistic operating and total cost figures.

SECTION II

INTRODUCTION

Frequently a sludge must be dewatered before it can be satisfactorily disposed of, and the dewatering process is one of the most costly involved in the handling and disposal of sewage solids. The quantities of sludges to be handled and the difficulties in handling and disposing of these sludges increase directly with the quality of the treated wastewater product.(1) The Federal Water Pollution Control Act Amendments of 1972 provide for improved wastewater quality including secondary treatment or its equivalent for municipal discharges by 1977.(2) In most cases this will require treatment plants to include biological treatment although in some it may only mean upgrading existing processes with chemical addition. Either alternative will cause more sludge to be produced, and this sludge will probably be more difficult to process.

Sludges which present a problem to mechanically dewater include waste activated and chemical sludges. This is partly because of their diluteness and partly because of their gelatinous nature. Presently very few municipalities will dewater only a waste activated sludge, even after first thickening it. It is almost always first combined with a primary sludge, even though it is well known that the presence of waste activated sludge increases the cost of dewatering primary sludge. Conventional dewatering equipment is unable to dewater straight waste activated sludge unless prohibitive quantities of chemicals are added.

The Westinghouse Electric Corporation over the last three years has been involved in developing a unique method to dewater dilute sludges. This work over the last year and a half has been supported under EPA contract specifically to answer the need for an economical mechanical dewatering system for use with unthickened waste activated sludge. Although thickened activated sludge and other sludge types were also evaluated, the proposed system should produce a truckable cake and/or a cake capable of undergoing combustion with minimum fuel requirements.

The system under development uses capillary action to initially dewater the sludge and form a thin sludge cake and it then employs mechanical compression to obtain a still drier cake. Both these dewatering steps are incorporated into a single system, endless belt design. A schematic of the device is shown in Figure 1. The endless belt portion of the device is actually comprised of two belts; a belt made of a porous material approximately 1/2 in. (13 mm) thick and a fine mesh screen belt.

To operate this device, the sludge is generally preconditioned, and then pumped onto the top at one end of the screen belt in a thin layer while both the porous and screen belts move towards the opposite end. The porous belt provides the capillary action for dewatering while the screen belt carries the sludge and serves to minimize clogging of the

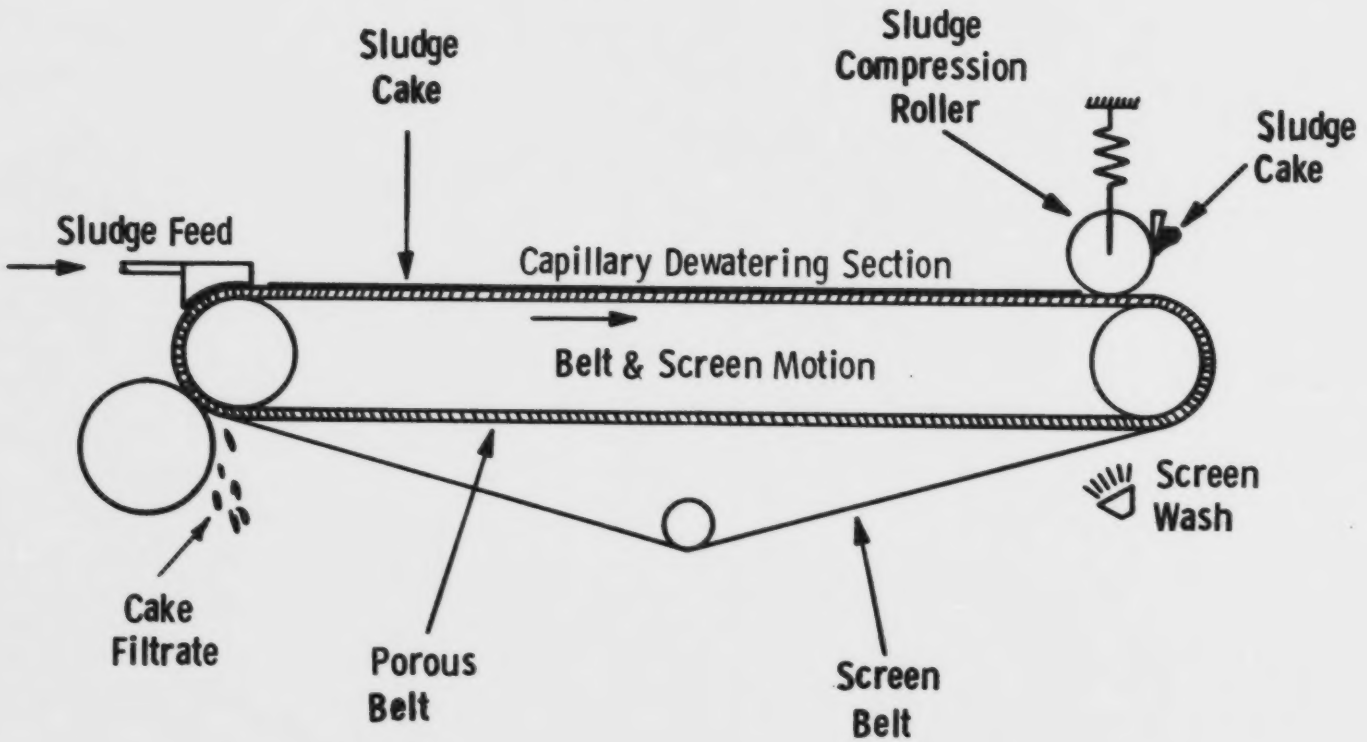


Fig. 1 –Schematic of research capillary dewatering unit

belt pores by the sludge solids. The porous belt, screen belt, and sludge are in direct contact which allows the free water associated with the sludge to be drawn preferentially by capillary forces through the screen belt into the porous belt. The sludge solids remain on the screen. By the time the sludge has reached the end of the capillary section of the machine, it has been transformed from its initial liquid form to a semi-solid thin sludge cake containing typically from 6 to 10 percent solids by weight. At this point, the sludge cake is passed under a compression roller causing additional water to be extracted. It has been found that the final solids of the cake depend on many factors but a 16 to 20 percent cake is typical for a waste activated sludge. This compression roller also serves as the sludge cake removal mechanism. The sludge cake after being compressed attaches preferentially to the roller surface and is lifted away from the screen belt. This provides for an effective method of detaching the thin sludge cake and thereby maintaining a high solids recovery. The water that was extracted from the sludge is contained within the porous belt and is subsequently squeezed-out and the belt and screen returned to the feed position.

The practice of using capillary action for solid liquid separation is not new (3,4), nor is the application of belt and sludge presses to sludge dewatering.(5) However, the capillary suction device described above is an improvement over prior systems in that it incorporates both these process operations in an arrangement that allows effective sludge dewatering and cake detachment with a minimum of energy expended. Moreover, the results of this study provide an improved technological basis of the design and performance of this capillary suction device.

The scope of this program has included both an evaluation of the basic mechanical functions of the device as well as a determination of specific design relationships. Machine performance on a pilot scale system was evaluated on three sludge types; the evaluation included first a determination of overall machine performance, such as system capacity and final cake solids, and secondly an evaluation of certain design parameters such as screen mesh size, capillary belt pore size, and compression roller force.

SECTION III

EXPERIMENTAL APPARATUS

CAPILLARY DEWATERING APPARATUS

Two experimental capillary dewatering test units have been operated. The first unit, shown in Figure 2, is a small scale system approximately 4 inches (10.1 cm) wide and 2 1/2 ft. (0.76 m) long (1 lit/min max. sludge feed rate). During the course of this program, this unit was used to generate the basic data for evaluating the mechanical operation of the system and determining parametric interactions. The second unit (or pilot unit), shown in Figure 3, is about 1 ft. (0.30 m) wide and 5 ft. (1.5 m) long and has six times the capacity of the smaller unit. This unit was built later and operated at a local sewage treatment plant to determine overall system operation and to substantiate results obtained from the smaller unit.

A schematic layout of the pilot test unit is given in Figure 4. Originally, this unit was designed so the porous belt and screen belt would track over separate drive rollers. This was later changed so that both the porous belt and screen belt track over the aft drive roller. The porous belt is driven by a combination of the tension force exerted around the aft roller and the drive force imparted to the belt by the set of compression rollers indicated in the schematic. This drive arrangement allows a minimum tension force on the porous belt thereby eliminating any belt stretch problems. The set of belt compression rollers also serve as the method of extracting the belt water (cake filtrate). Three water spray nozzles are located beneath the aft drive roller and are used to wash the screen belt which, at this location, is separated from the porous belt. The cake filtrate and wash water streams are maintained and sampled separately. The porous and screen belts are driven from a 1/2 hp (40 Kg-m/sec) variable speed motor using chain and sprocket drives. Screen material used in the program was a dacron polyester supplied by Wire Cloth Enterprises, Pittsburgh, Pa. Porous belt material was a nylon, needle punched felt of approximately 7 oz/ft^2 density (2.2 Kg/m^2) supplied by Orr Felt Company, Piqua, Ohio.

The general arrangement of the test unit, sludge and chemical feed pumps is given in Figure 5. The sludge was drawn from the sewage plant at the return line using a positive displacement 2.0 gal/min (7.5 lit/min) pump and a 2-inch (52 mm) line. Sludge for the dewatering unit was drawn from this line via a smaller (0-6 lit/min) pulsation pump. The unused sludge was circulated back to the primary treatment tank. This arrangement provided fresh sludge continuously. Coagulant was prepared in stock solutions and pumped from a holding tank into the sludge line on the output side of the pulsation pump. There were approximately 3 ft. (1 m) of 3/4 inch (19.0 mm) tubing in which the sludge and coagulant were mixed before spilling into the feed tray. The feed tray utilized a splitter plug to dampen flow variations, thus assuring a uniform sludge layer onto the dewatering unit.

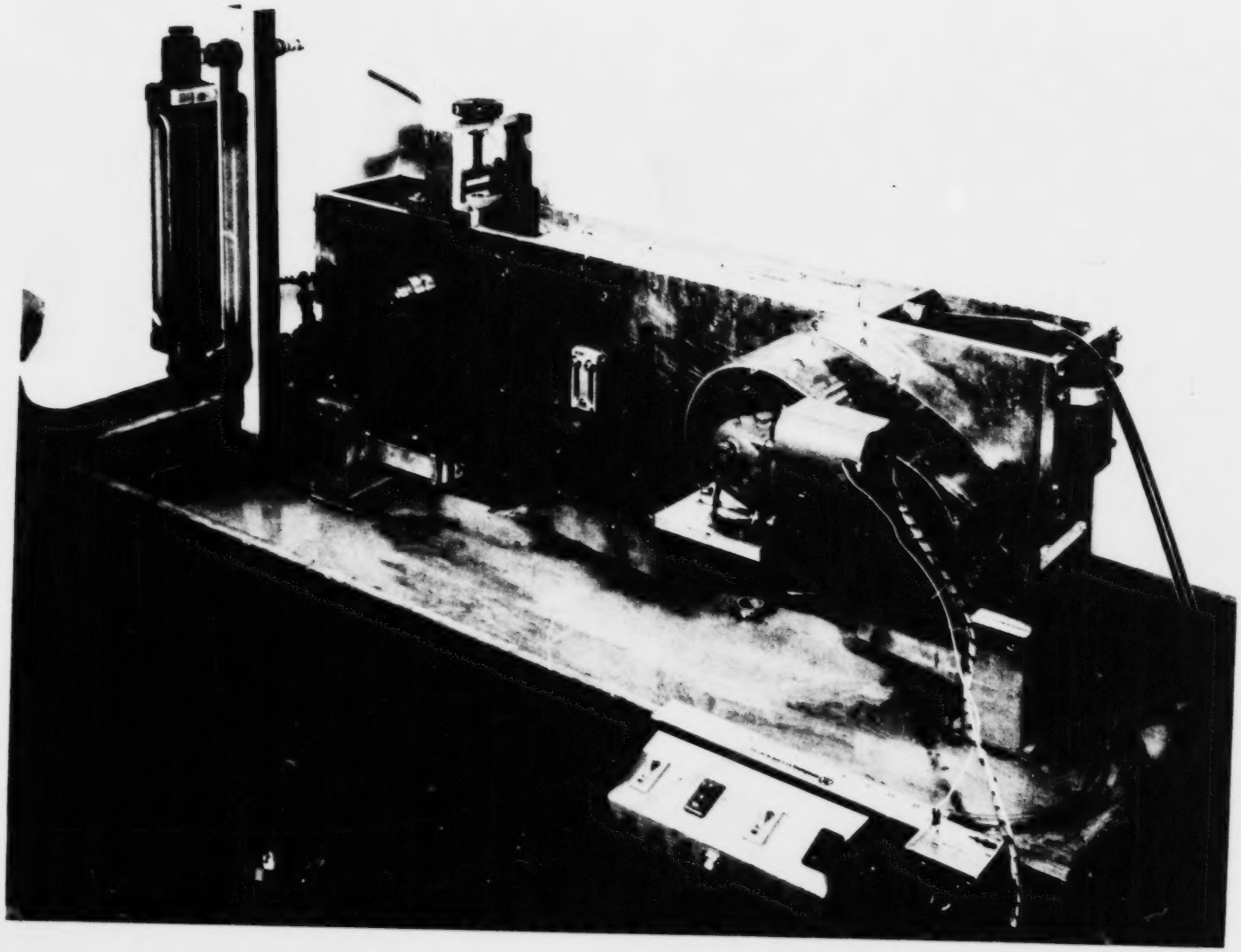


Fig. 2 - Laboratory capillary dewatering unit

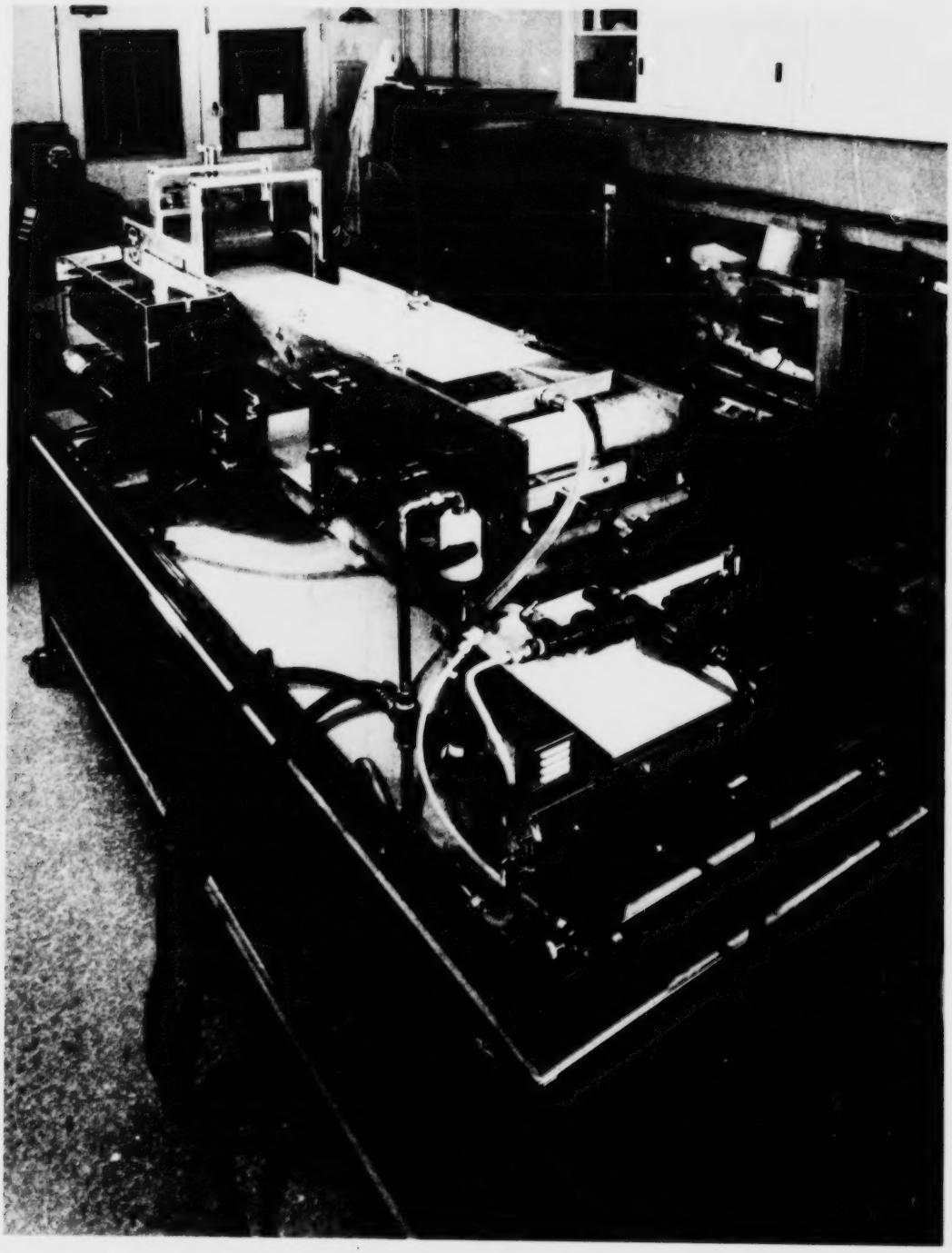
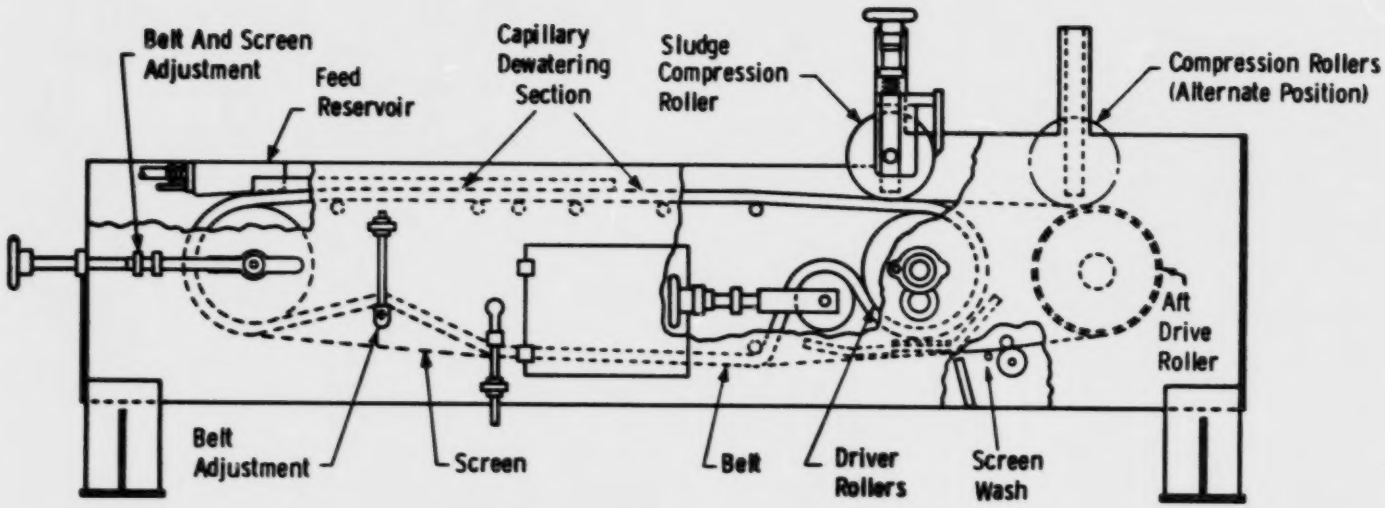


Fig. 3 - Capillary dewatering pilot test unit.



Scale 1 cm ≃ .13 Meters

Fig. 4— Schematic of demonstration test unit

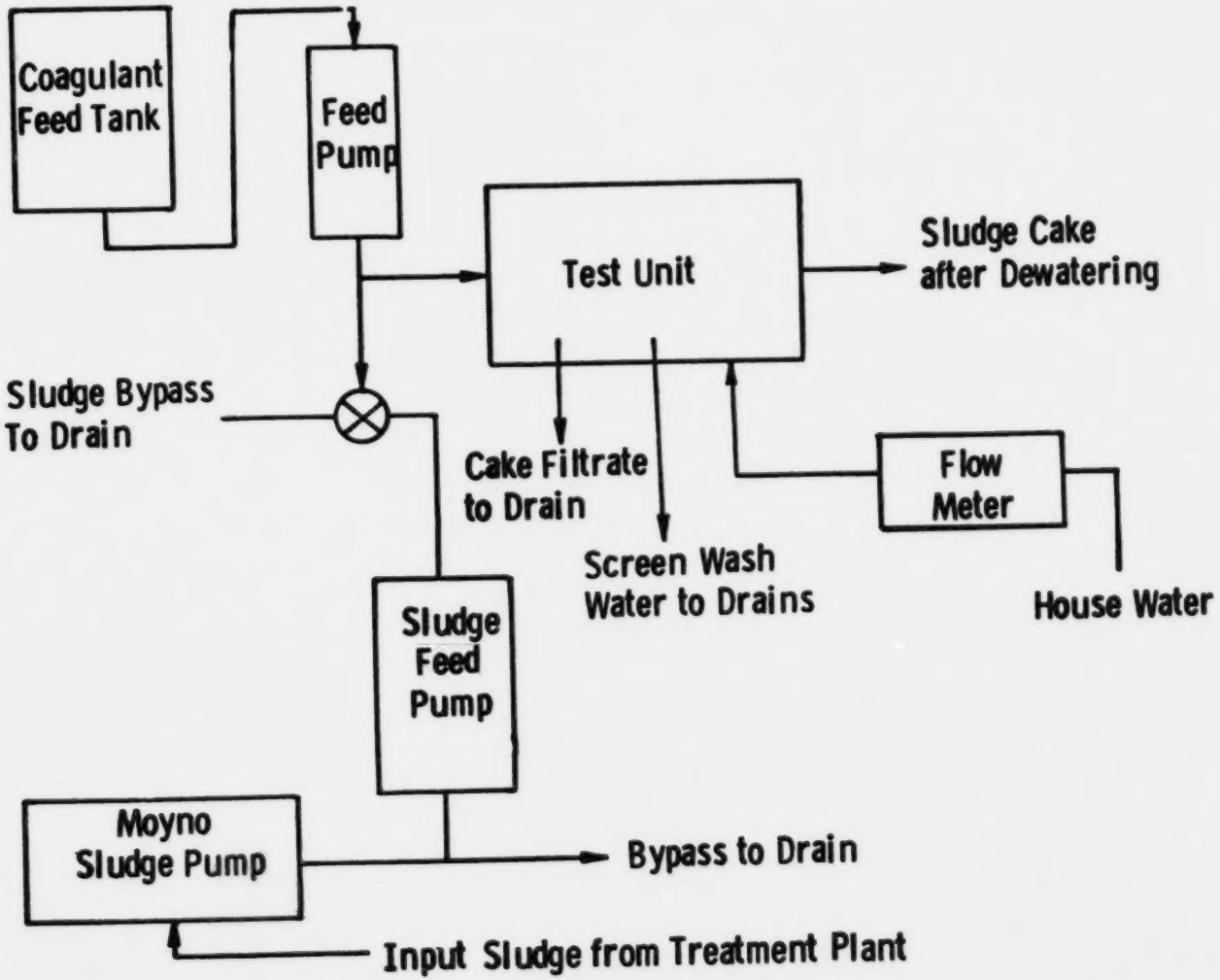


Fig. 5—Schematic of system set-up

LONG ROAD SEWAGE PLANT FACILITY

Available for the study of municipal sludges was a Westinghouse operated test facility, shown in Figure 6, located at the Long Road Municipal Sewage Treatment Plant. The plant, located in Penn Hills, Pennsylvania, uses the spiral diffused aeration activated sludge process to treat 1 mgd (4 million liters/day) of municipal sewage. Figure 7 is a schematic of the treatment process and illustrates the flow of waste. Recycle activated sludge from the final clarifier is wasted through a primary clarifier. Sufficient activated sludge solids are wasted so that a sludge age of three days can be maintained in the aerator. The combined sludge solids from the primary clarifier are digested and dewatered by a vacuum drum filter. Available for this study, therefore, for processing by the capillary dewatering unit were activated, mixed primary, and digested sludges. Table 1 below lists the average sludge characteristics, which were compiled from data taken during this test program. Plant influent BOD and suspended solids averaged 150 and 180 mg/l respectively.

It should be noted that this activated sludge is relatively high in solids content. They carry an unusually high aeration cell mlss concentration and achieve good settling characteristics. Because of the high solids content, the sludge may be partially stabilized aerobically in the aeration cell resulting in low values of mlvss. This plant feed also is almost exclusively municipal in character with practically zero industrial load which may account for the relatively low dissolved solids level. Tap water TDS in this area normally is in the range of 200 mg/l.

Table 1

	Sludge type		
	Activated	Mixed primary	Digested
Total solids (mg/l)	19,545	40,480	48,235
Total volatile solids (mg/l)	10,620	23,310	23,425
Dissolved solids (mg/l)	840	1,572	1,280
Dissolved volatile solids (mg/l)	200	646	860
pH	6.9	6.3	7.1
Sludge specific resistance (sec^2/gm) x 10^{-8}	17.3	40.0	3.89

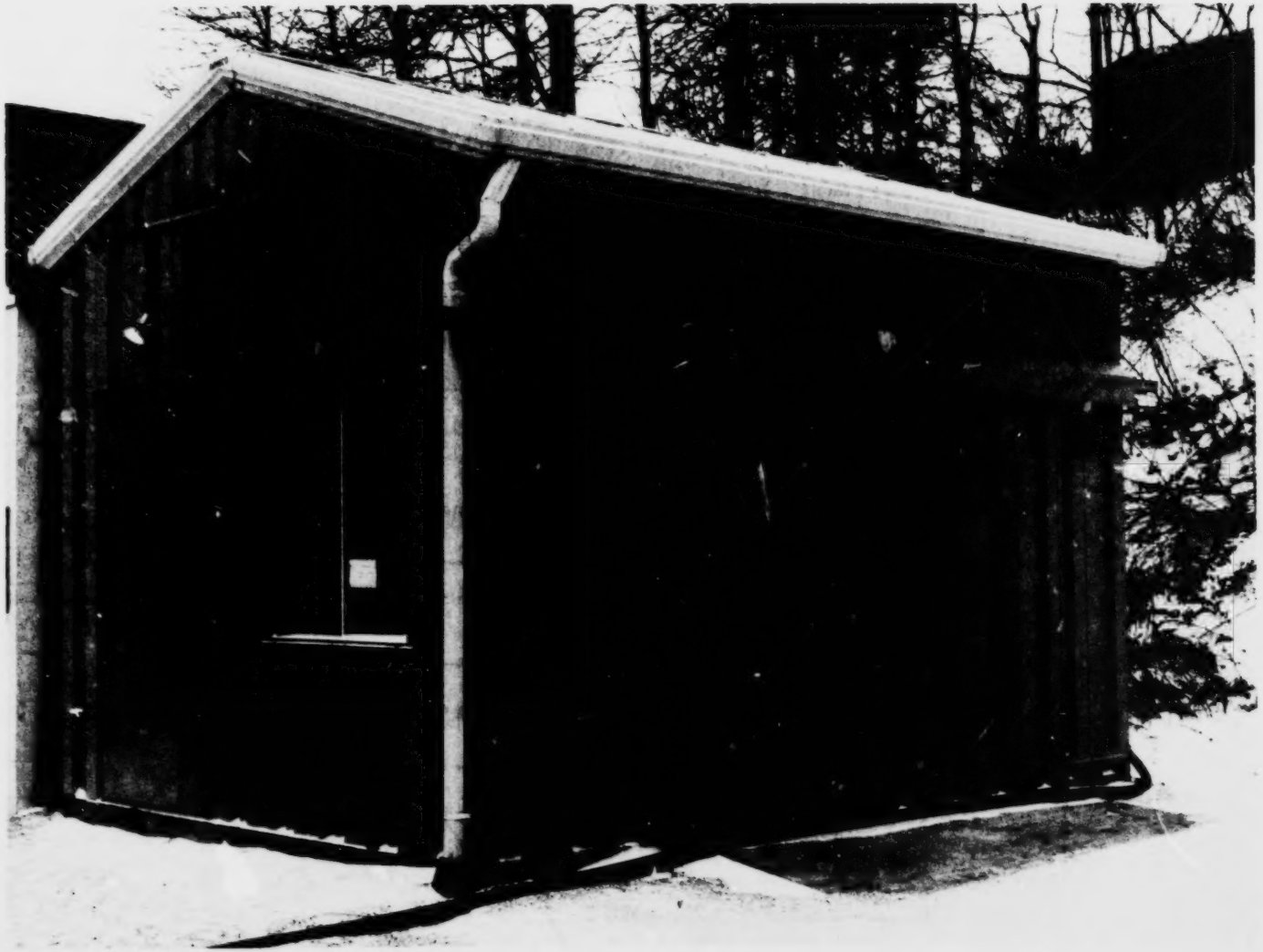


Fig. 6 - Westinghouse test facility at the Long Road Sewage Plant

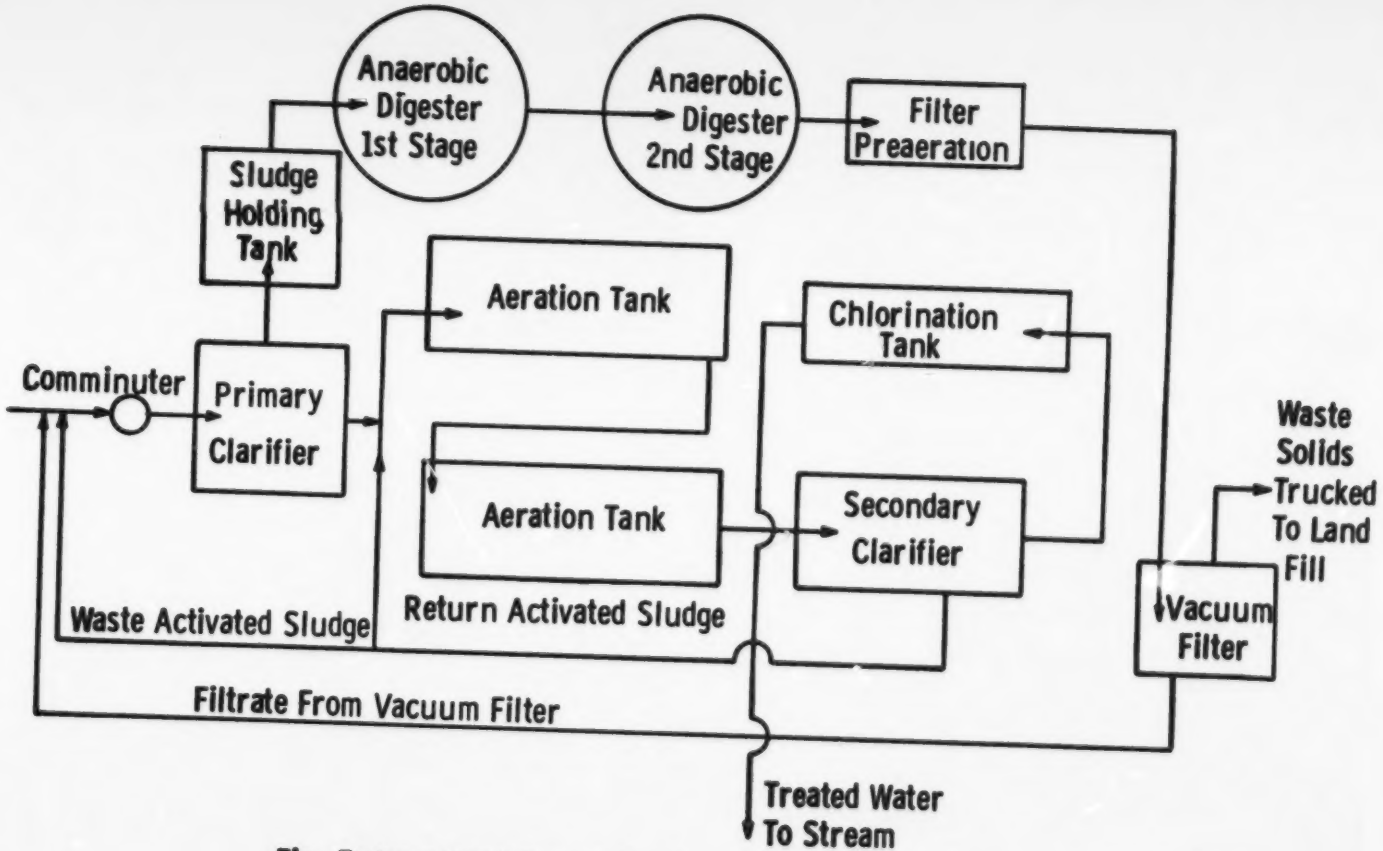


Fig. 7—Long Road Sewage Treatment Plant - flow schematic

To further characterize these sludges, specific resistance determinations were made on each sludge type according to the procedure described in Reference 6. The specific resistance values recorded in the table above are for no coagulant addition. Figures 8, 9, and 10 show the specific resistance values of these sludges as a function of coagulant dosage. Several different coagulants were evaluated. This data was used to set approximate coagulant levels for the sludges used in tests on the capillary dewatering device.

BELT-LIFE TEST APPARATUS

As part of this program, a continuing life test evaluation on several swatch samples of different porous media was made using the apparatus shown in Figure 11. Photographs of the swatch test samples are given in Figure 12. The various samples were attached to the endless metal belt. The apparatus was partially filled with activated sludge (about 0.3m depth) and the swatch samples tracked through the sludge. The sludge was continuously aerated and also changed approximately every three days. A small compression roller was situated such that each swatch sample would pass under the roller and be slightly compressed. This was done in order to approximately simulate the mechanical loading expected in the actual capillary dewatering device. This test apparatus was operated about one year.

TEST PROGRAM AND PROCEDURE

The test program on the pilot scale capillary dewatering unit was conducted at the Westinghouse facility located at the Long Road Sewage Plant. This test program included operation of the capillary dewatering device on activated, mixed primary-activated, and anaerobically digested sludges. The experimental design was organized such that an overall machine performance and operation could be determined as well as an evaluation of specific system operating parameters such as coagulant dosage effects, belt speed, roller compression force, etc. Day to day test runs generally lasted from 2 to 6 hours. More than 300 total hours were accumulated in the operation of the test unit.

Start-up procedure involved preselecting belt speed, sludge feed rate, and coagulant dosage. The compression roller force was selected (except in certain specific tests) such that satisfactory operation of the compression station could be maintained. This generally involved manipulating the roller spring deflection to achieve the best cake detachment efficiency possible, while, at the same time, obtaining the highest cake solids. These judgements were based on prior experience.

Test data was taken only after sufficient time (usually 15 to 30 minutes) was allowed for attaining equilibrium operation. This same procedure for data taking was practiced whenever any of the operating parameters were varied.

Routine test measurements included sludge feed rate, coagulant feed rate, sludge cake dry solids, screen wash water flow rate, cake filtrate flow, and compression roller spring deflection. In addition, the feed sludge was sampled and analyzed for total, volatile, dissolved solids and dissolved volatile solids. These constituents were analyzed in accordance with procedures outlined

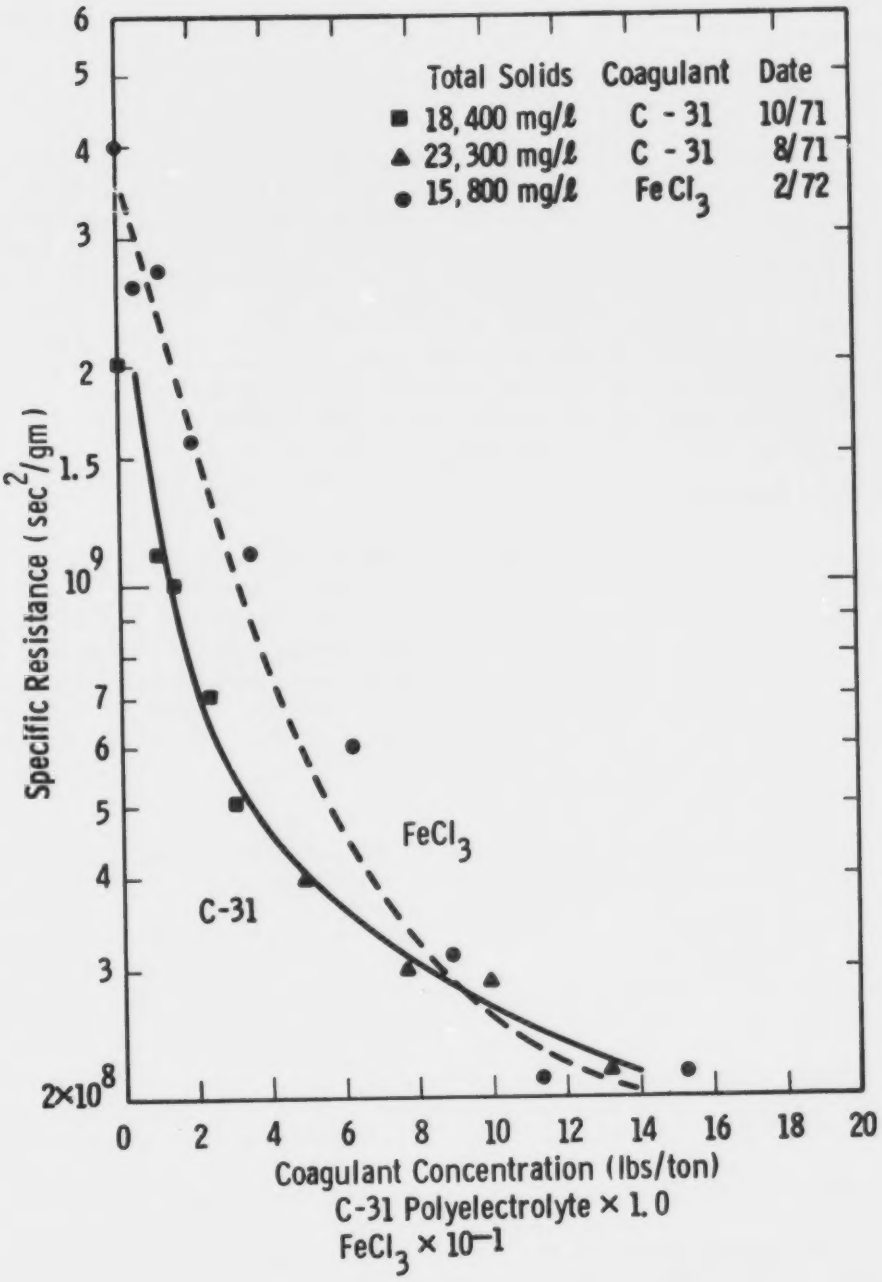


Fig. 8—Sludge specific resistance - waste activated sludge
(Kgs/ton (m) = 2.0 lbs/ton)

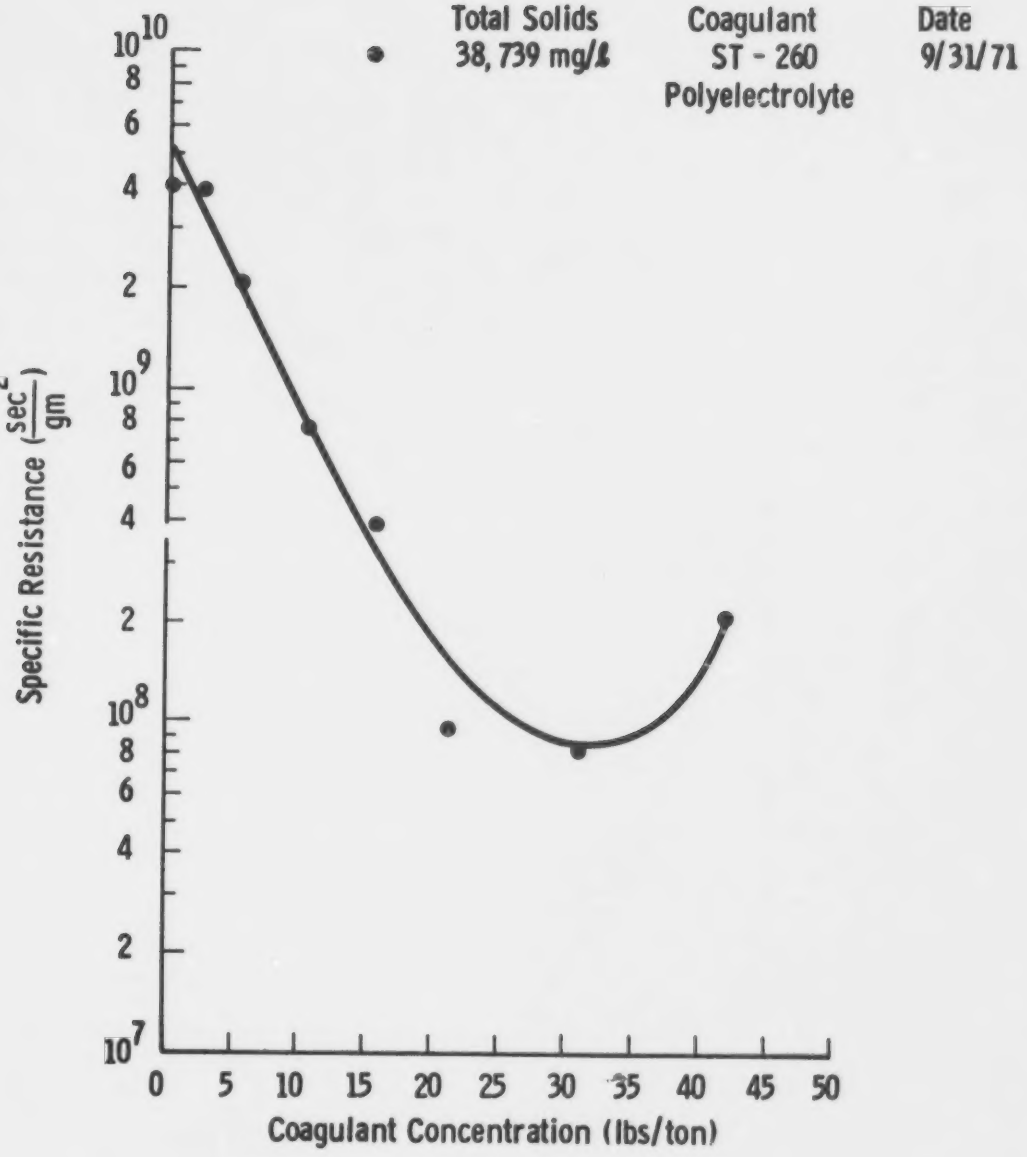


Fig. 9—Sludge Specific Resistance - Mixed Activated - Primary
(Kgs/ton (m) = 2.0 lbs/ton)

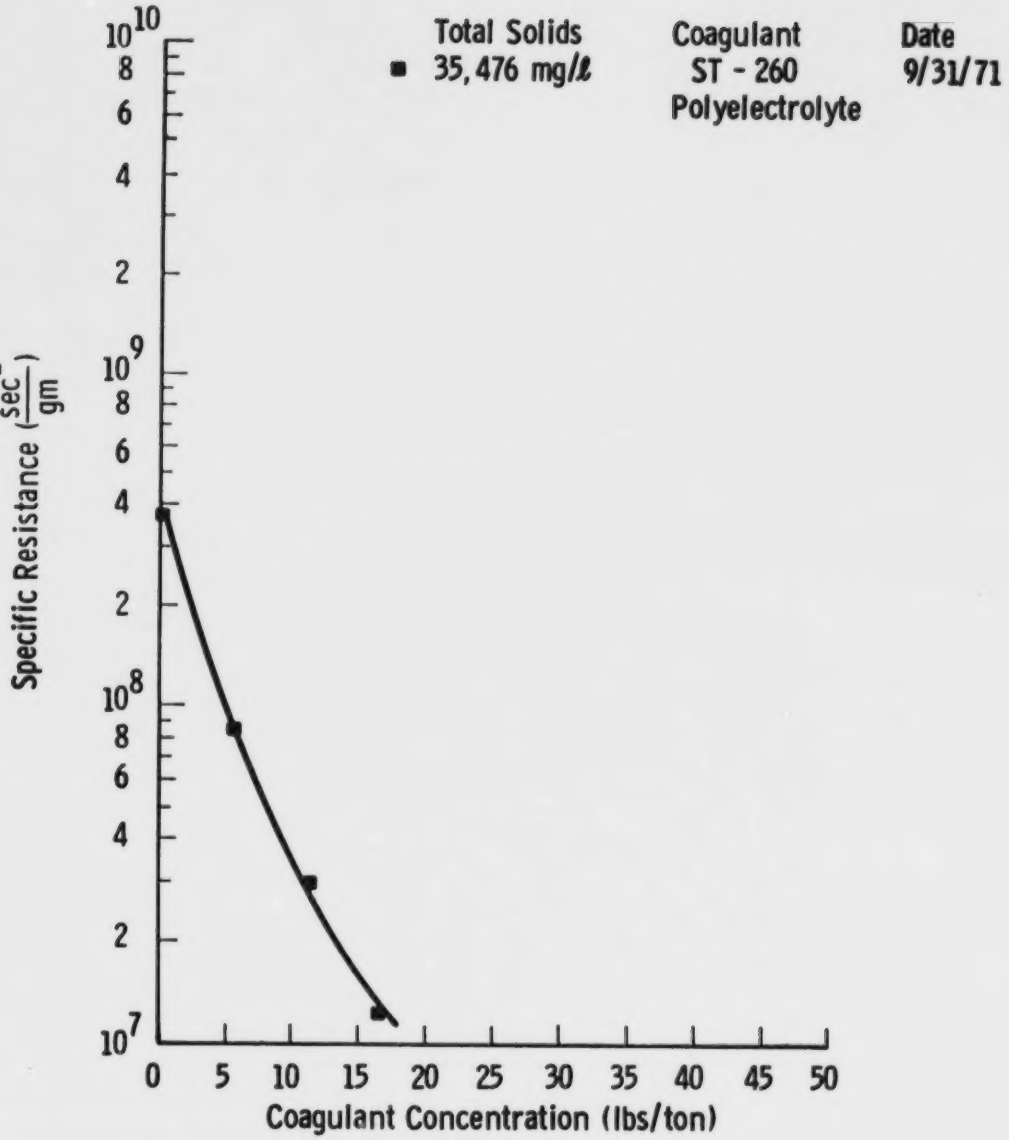


Fig. 10—Sludge Specific Resistance - Anaerobically Digested
(Kgs/ton) m) = 2.0 lbs/ton)

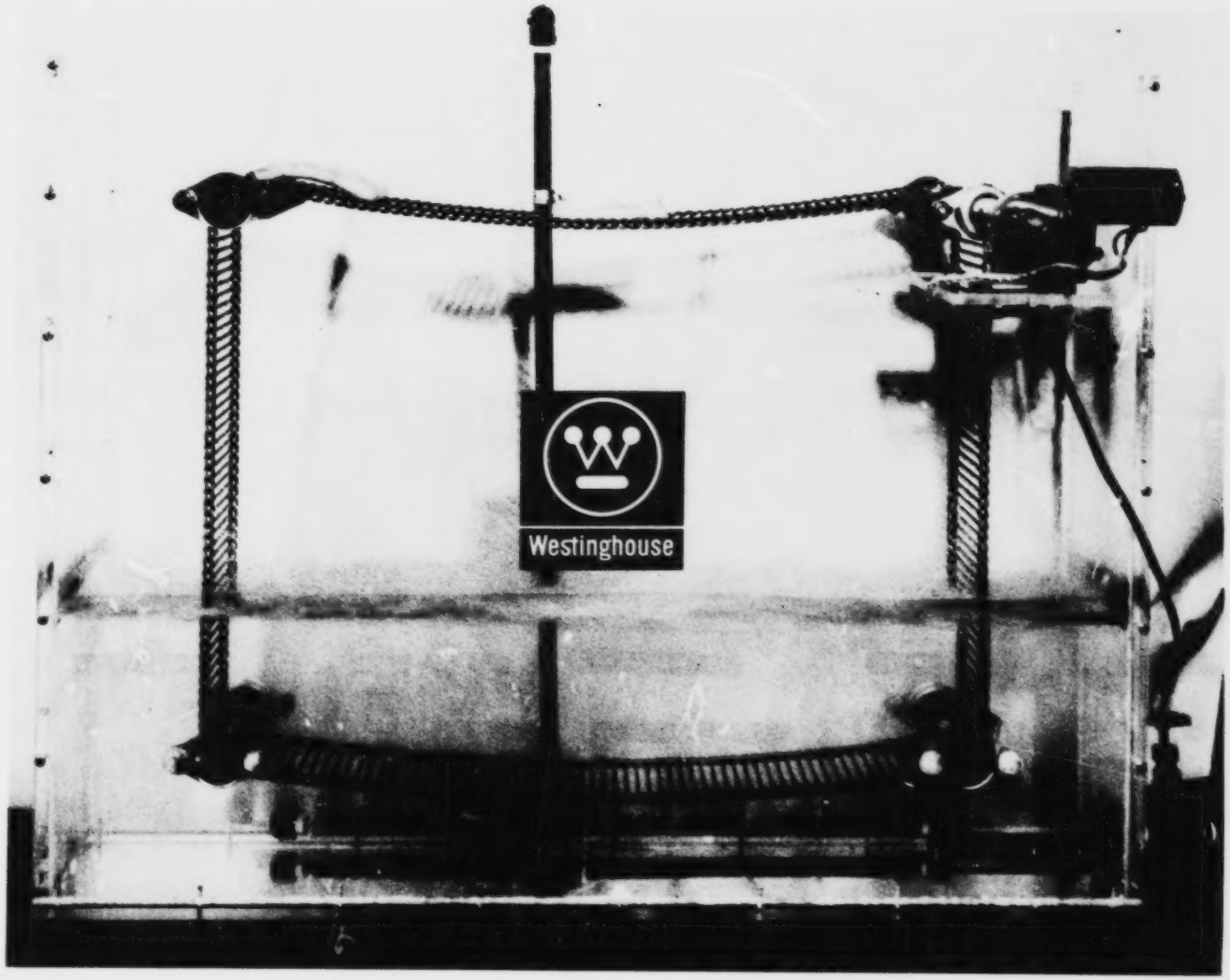


Fig. 11 - Endless belt life test apparatus for evaluating porous media swatch samples.

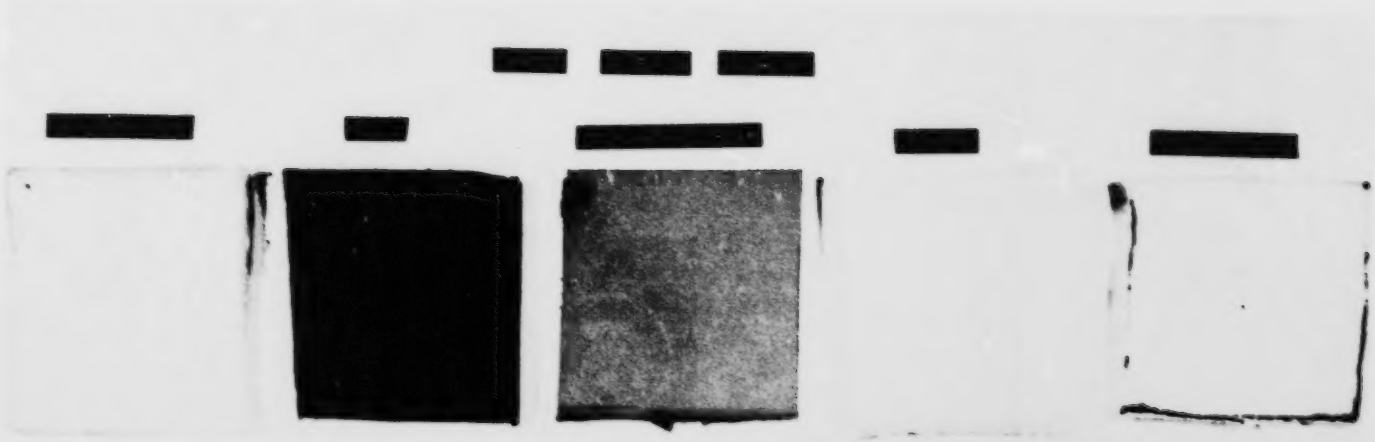


Fig. 12 - Porous media swatch samples before entering sewage.

Date: 12/4/72

Run: 1204 Cross Reference Nos.: 1766190-91

Sludge Characterization

Type sludge Activated

Total solids 19,500 mg/l

Total dissolved solids 9800 mg/l

Dissolved solids 800 mg/l

Dissolved volatile solids 125 mg/l

pH 6.9

Machine Parameters

Sludge feed rate 6.5 l/min

Belt-sludge contact time 3.5 sec.

Coagulant type C-31

Coagulant concentration 18.7 #/ton

Run time start 217.7 finish 219.2

Sample No.	Inches Along Belt	Sludge Cake Dewatering Characterization			Filtrate Characterization				Machine Performance		
		Before Comp.	After Comp.	Other * g/min	Belt Water		Screen Wash Water		Solids Loading (lbs/ft^2)	Solids Recovery %	Solids Loading Rate (lbs/hr ft^2)
		T.S.	T.S.	T.S.	Quan. ℓ/min.	T.S.	Quan. ℓ/min.	T.S.			
930	5	5.9			6.4				.0045		
931	10	8.3			6.4				.0045		
932	15	9.8			6.4				.0045		
933	20	10.4			6.4				.0045		
934	25	10.6			6.4				.0045		
935	30	10.7			6.4				.0045		
936	35	11.0			6.4				.0045		
937	40	11.0			6.4				.0045		
938	50	11.0			6.4	2920			.0045	88.6	4.63
939			14.5	112.8	6.4				.0045	92.2	4.63

*Roller sample for total solids balance.

Compression Roller

Load--in. deflection in springs 1/2 inch (12.4 #/in) Belt squeegee

Pickup efficiency

NOTES: 300 mesh screen

Table 2 - Sample Data Sheet (after sample analysis)

in the Standard Methods for the Examination of Water and Wastewaters or EPA approved alternate methods. Sludge pH was also occasionally monitored. A sample data sheet is shown in Table 2. The cake solids capture (indicative of cake process water quality) was determined by two methods; first by determining for a given time increment the actual dry sludge solids discharged from the compression roller and comparing this with the measured solids in the feed stream, and secondly by calculating cake solids capture from a mass balance on the feed stream, sludge filtrate and wash water flows. These two methods generally agreed to within a few percentage points.

An estimate of the error involved in the measurement and reproducibility of each of the basic test parameters is given in Table 1-A in Appendix A. The cumulative effect of these errors on the various calculated quantities is given in Table 3 below. Further discussion of the error analysis procedure including some sample calculations is also given in Appendix A.

Table 3. EXPECTED UNCERTAINTY IN THE CALCULATED QUANTITIES

Parameter	Typical value	Expected maximum deviation
1. Sludge feed rate		
a. Activated sludge	2.4 l/min	$\pm$2.4%
Activated sludge	6.5 l/min	$\pm$3.5%
b. Digested sludge	3.0 l/min	$\pm$6%
c. Mixed primary	3.5 l/min	$\pm$6%
2. Machine capacity		
a. Activated sludge	2.0 lbs/hr ft^2	$\pm$4.1%
Activated sludge	5.0 lbs/hr ft^2	$\pm$4.8%
b. Digested sludge	5.0 lbs/hr ft^2	$\pm$7%
c. Mixed primary	5.0 lbs/hr ft^2	$\pm$7%
3. Solids capture		
a. Activated sludge	90%	+5.3% -4.1%
b. Digested sludge	85%	+7% -6.4%
c. Mixed primary	85%	+7% -6.4%
4. Coagulant concentration Level	4 lbs/ton (2 Kg/metric ton)	$\pm$10%

(1 lb/hr $ft^2 \simeq$ 5 Kg/hr m^2)

SECTION IV

DISCUSSION OF RESULTS

SUMMARY OF CAPILLARY SUCTION DEVICE SYSTEM PERFORMANCE

The performance of most mechanical sludge dewatering devices is measured by at least four parameters; system capacity (Kgs d.s./hr m^2), final cake solids (%), solids capture (%) and total costs ($/Kgs d.s.). Following the convention used for rotary vacuum belt filters only the working area of the belt is used in the calculation of machine capacity.

Sufficient test data has been generated from this program, both from the small lab test unit and from the larger pilot unit, to indicate how these specific performance parameters are influenced by changes in the various operating and machine design variables. For example, trends have been determined indicating how certain screen parameters affect sludge solids capture and therefore coagulant costs or similarly, how the sludge solids loading affects dewatering rate and thus machine capacity. A summary listing of all the data obtained from the pilot unit is given in Tables 1-B through 4-B in Appendix B. These data reflecting these parametric interactions are discussed in subsequent sections of this report. However, before examining this data, a general summary of machine performance is presented in order that the overall program results can be succinctly identified.

Table 4 below summarizes the performance data obtained with the pilot test unit while operating at the Long Road Sewage Plant on waste activated, anaerobically digested, and a mixed primary/activated sludges. This unit was operated for approximately nine months and more than 300 actual operating hours were accumulated during this study.

Table 4. SUMMARY OF PILOT PLANT CAPILLARY DEWATERING SYSTEM PERFORMANCE

Sludge type	Machine capacity (lbs/hr ft^2)	Coagulant cost ($/ton)	Final cake solids (%)	Solids recovery (%)
WAS	2.0	0	16-19	60-75
WAS	2.0	4.00 (C-31, Polyelectolyte)	17-19	95
WAS	3.0	0	16	50-65
WAS	4.3	6.40 (Ferric Chloride)	15	91
WAS	4.5	4.00 (C-31, Polyelectrolyte)	14-15	80
DIGST	5.2	10.00 (Ferric Chloride)	16-18	88
MIXPRIM	5.4	10.00 (Ferric Chloride)	14-15	85

(Kgs/m^2 = 0.205 lbs/ft^2)

($/Ton = $1.1/metric ton)

The results recorded in Table 4 typify machine performance on the various sludge types at several coagulant dosage and sludge feed rates. The cost figures reported in the table represent coagulant requirements only since the capital and operating costs of this test unit are not indicative of a full scale system. Estimates of this cost for a full scale system are given in Appendix C. Coagulant costs were taken as $.40/lb ($.88/Kg) for the polyelectrolyte and $.05/lb ($.11/Kg) for the ferric chloride.

As shown in the table, the test unit was operated both with and without chemical conditioning. With the activated sludge at a feed rate of 2.0 lbs d.s./hr ft^2 (10 Kgs/hr m^2) and a coagulant demand (polyelectrolyte C-31) corresponding to $4.00/ton d.s. ($4.40/metric ton), final cake solids ranged around 18 percent with solids recovery as high as 95 percent. An 18 percent cake represents about a 90 percent reduction in the sludge volume and a cake of "truckable" consistancy. Final cake solids did not appear to depend significantly on coagulant addition but did decrease slightly when the machine feed rate was increased from 2.0 to 4.6 lbs/hr ft^2 (10 to 22 Kgs/hr m^2). Cake solids recovery, however, was found to depend strongly on coagulant addition and to a lesser extent on feed rate. With no coagulant addition, solids recoveries were found to vary from 60 to 75 percent at the lower feed rates and measured as low as 50 percent at the higher rates. With coagulant addition, cake solids capture improved dramatically; to 95 percent with the polyelectrolyte at the lower feed rates. Comparable solids recoveries are possible at the high feed rates but at an increased coagulant cost.

In general, it was found that the ferric chloride coagulant yielded better overall performance i.e., dryer cake and better cake detachment than the polyelectrolyte. To achieve comparable solids recoveries with the ferric chloride conditioner, dosage rates around 200 lbs/ton (100 Kgs/metric ton) are indicated.

Reported data on the mixed primary-activated sludge was limited to just one feed rate and only the ferric chloride conditioner. A final cake containing 15 percent solids with 85 percent solids recovery was achieved. This is a ferric dosage rate of 246 lbs/ton (123 Kgs/metric ton) with a machine loading of 5.4 lbs/hr ft^2 (26 Kgs/m^2 hr).

With the anaerobically digested sludge, and a machine loading of 5.4 lbs/hr ft^2 (26 Kgs/m^2 hr), solids recoveries in excess of 90 percent were attained with a ferric chloride dosage of approximately 300 lbs/ton (150 Kgs/metric ton). The final cake solids varied from 16-18 percent. Assuming a 5 cent/lb (11 cents/Kg) cost for the ferric chloride, chemical costs for dewatering the mixed primary and the digested sludges ranged from $10.00 to $15.00/ton ($11 to $16/metric ton), respectively.

Further consideration is given to the test data in Table 4 in subsequent sections where it is shown how the machine capacity, final cake solids and cake capture relate to the various machine operating and design variables. Test data obtained from the smaller lab unit and from the belt life test unit is also discussed.

MACHINE DESIGN AND SYSTEM CAPACITY

The physical size of this dewatering device is obviously determined by the physical size of the capillary zone. Thus, the efficiency of the capillary dewatering in forming the sludge cake represents an important design consideration. With activated sludge, it has been learned through experience that an 8 percent (solids) cake is needed at the end of the capillary zone before passing into the sludge compression zone. With wetter cakes, operational problems with the compression roller may be encountered. Some examples of quantitative measurements made of cake formation along the capillary zone are given by the sludge dewatering curves shown in Figure 13. The data is for a waste activated sludge with 2 percent solids that was conditioned by the addition of 40 mg/l of a cationic polyelectrolyte. This data was obtained by determining the cake solids from sludge samples taken at various positions along the length of the capillary section of the small test unit. Two sets of data are shown, one for a solids loading of 0.005 lbs/ft^2 (0.024 Kgs/m^2) and the other for a loading of 0.012 lbs/ft^2 (0.58 Kg/m^2). As seen, the two sets of data exhibit a similar trend in that the rate of water extraction is highest initially and decreases exponentially as the sludge becomes concentrated. The curve for the lower solids loading shows a 10 percent cake is achieved in less than a 10 second sludge-belt contact time while an 8 percent cake in 20 seconds is indicated for the higher solids loading condition. Thus, both the cake solids and the time needed to dewater the sludge depend on the sludge solids loading. A system optimization must consider therefore both these parameters.

By developing a family of these sludge dewatering curves, a basis was established for designing and operating the capillary section of the machine. The results of this data for the activated sludge is given by the curve in Figure 14. This curve shows machine capacity as a function of solids loading. The curve is for a 2 percent waste activated sludge conditioned with 40 mg/l cationic polyelectrolyte and, furthermore, assumes an approximate 9 percent cake at the end of the capillary section. This curve was developed from data obtained from the small lab unit while the data points shown represent actual operating data from the pilot unit. The majority of these data points reflect machine performance using the polyelectrolyte conditioner. One data point is shown however, in which the ferric chloride conditioner was used.

The data in Figure 14 show that the highest machine capacities are achieved at the lowest solids loading i.e., when the sludge is applied in a very thin layer. Rates in excess of 6.0 lbs/hr ft^2 (30 Kgs/hr m^2) are indicated corresponding to a solids loading of 0.004 lbs/ft^2 (0.019 Kgs/m^2). It was found, however, that when the solids loading was decreased below 0.003 lbs/ft^2 (0.014 Kgs/m^2) the sludge layer was so thin that it would not distribute uniformly over the screen belt and therefore surface area utilization was diminished. This would represent then a lower operational limit on the sludge solids loading. An upper operational limit on solids loading occurred when the sludge layer became too thick to be effectively compressed by the roller. This occurred at about a loading of 0.03 lbs/ft^2 (0.15 Kgs/m^2).

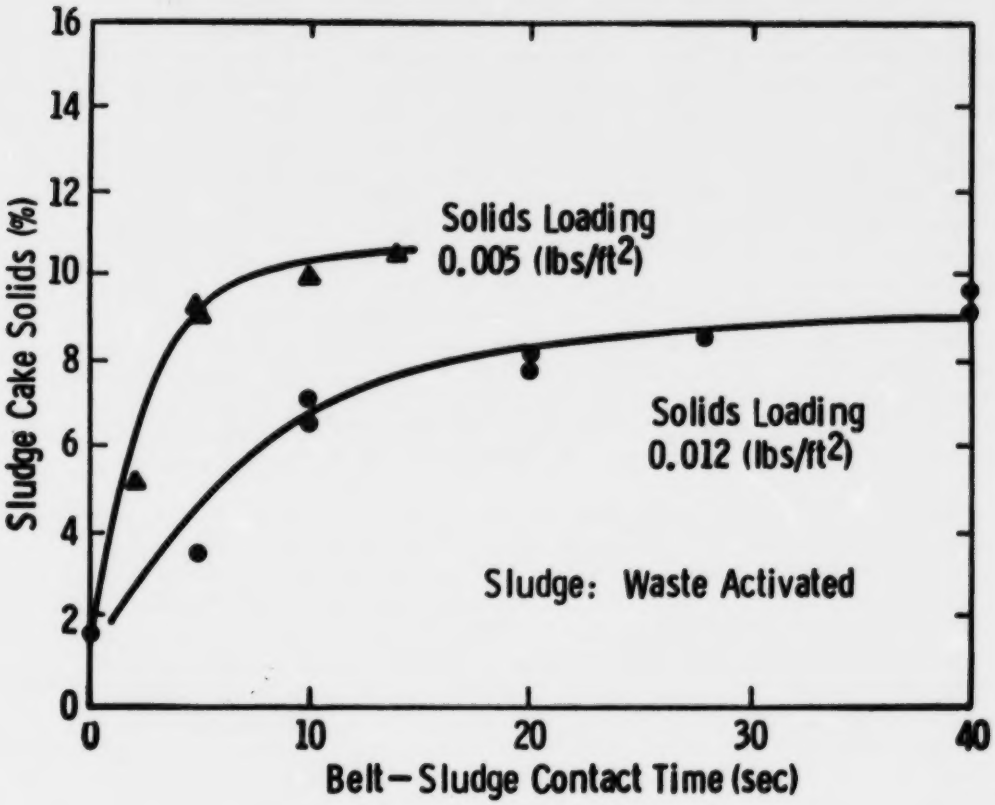


Fig. 13– Sludge capillary dewatering curves
(kgs/m^2 = 0.205 lbs/ft^2)

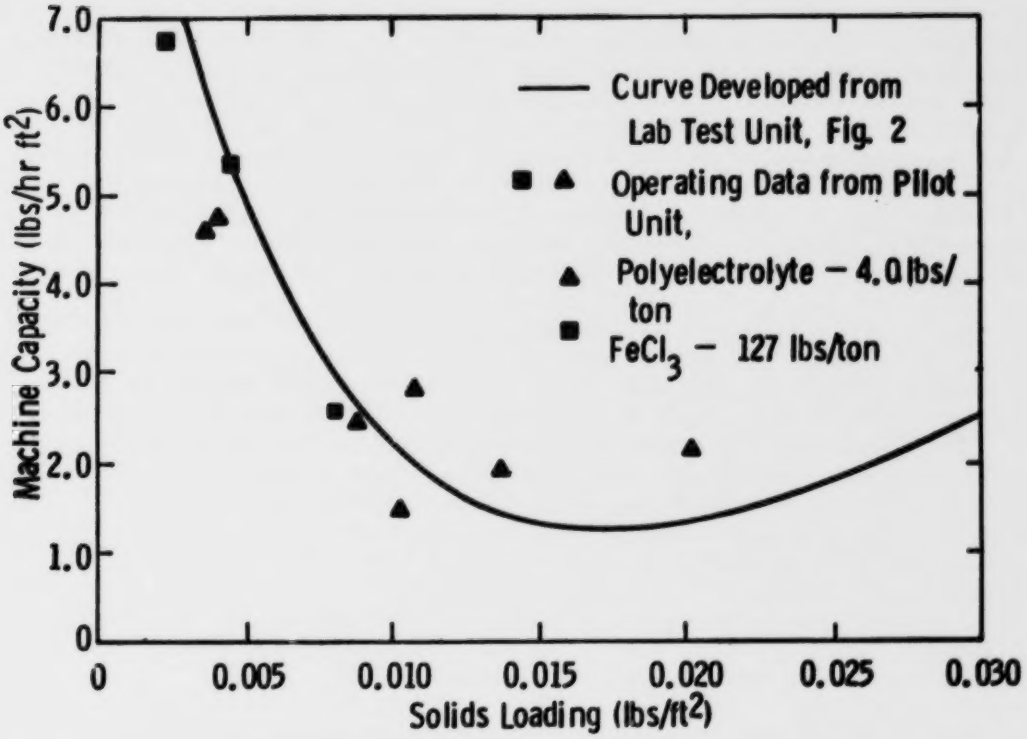


Fig. 14– Capillary dewatering–machine capacity with waste activated sludge (kgs/m^2=0.205 lbs/ft^2, kgs/ton(m) =2.0 lbs/ton)

Of fundamental importance, the curve in Figure 14 shows that the actual capillary dewatering phenomena is governed by several different rate limiting mechanisms which depend on the sludge solids loading. At very low solids loadings the sludge cake is thin and its resistance to dewatering is minimal. Hence, the controlling factors are the rate at which water is absorbed by capillary action into the belt and the total quantity of water that must be transferred. As the solids loading is increased (i.e., a thicker sludge cake), the cake resistance per unit of belt surface area increases in greater proportion than the solids weight. Therefore, the dewatering rate decreases. This continues until a point is reached where a pore flow is established in the cake and further increases in solids loading no longer produce a proportionate increase in cake dewatering resistance. This represents the minimum point observed in the curve. Further increases in solids loading i.e. increase in dry solids weight, result in increasing machine capacity. This continues until the hydraulic capacity of the porous belt is exceeded.

Sufficient data was not obtained to develop design curves for the mixed primary and the digested sludges. It can be argued, however, that the design curve for these sludges should be very similar to that of activated sludge if these latter sludges are similarly conditioned i.e., conditioned to allow free water drainage. This observation is somewhat supported by the limited data that was obtained for the mixed primary and the digested sludges as seen when these data are compared with curve developed for the activated sludge case, Figure 15. The significance of this result is that the design of the capillary section may be independent of the initial solids concentration of the sludge providing (1) that the system can be designed to handle the water hydraulics at the desired solids loading and (2) the free water in the sludge can be extracted by capillary forces. The first qualification applies to very dilute sludges while the second is a limiting condition on the more concentrated sludge types.

The practical utility of the design curve in Figure 14 is two fold; first it serves initial design purposes for determining the physical size of a unit for a given plant size and secondly, the curve can be used to adjust machine operating conditions i.e., belt speed to maximize capacity in any off-design condition.

The relatively high machine capacities that are indicated by the data in Figure 14 are the result of minimizing cake dewatering resistance by controlling sludge solids loading i.e., cake thickness. Another method of decreasing cake resistance and therefore increasing machine capacity is by increased coagulant dosage. This is seen from the data given in Figure 16 where the capacity of the pilot test unit was determined as a function of coagulant dosage for a fixed solids loading. The reference data points, shown unshaded, are machine capacities calculated by sampling the sludge layer at different positions along the length of the machine and determining the effective belt surface area needed to dewater the sludge to about a 9 percent cake. This is the same basis used to develop the curve in Figure 14. The results from Figure 16 show that when coagulant dosage is increased from 4 to 20 lbs/ton (2-10 Kg/metric ton) of the polyelectrolyte, machine capacity is increased from 4.6 to a maximum of 8.0 lbs/hr ft^2 (40 Kgs/hr m^2) but a further increase in coagulant diminishes capacity. Likewise,

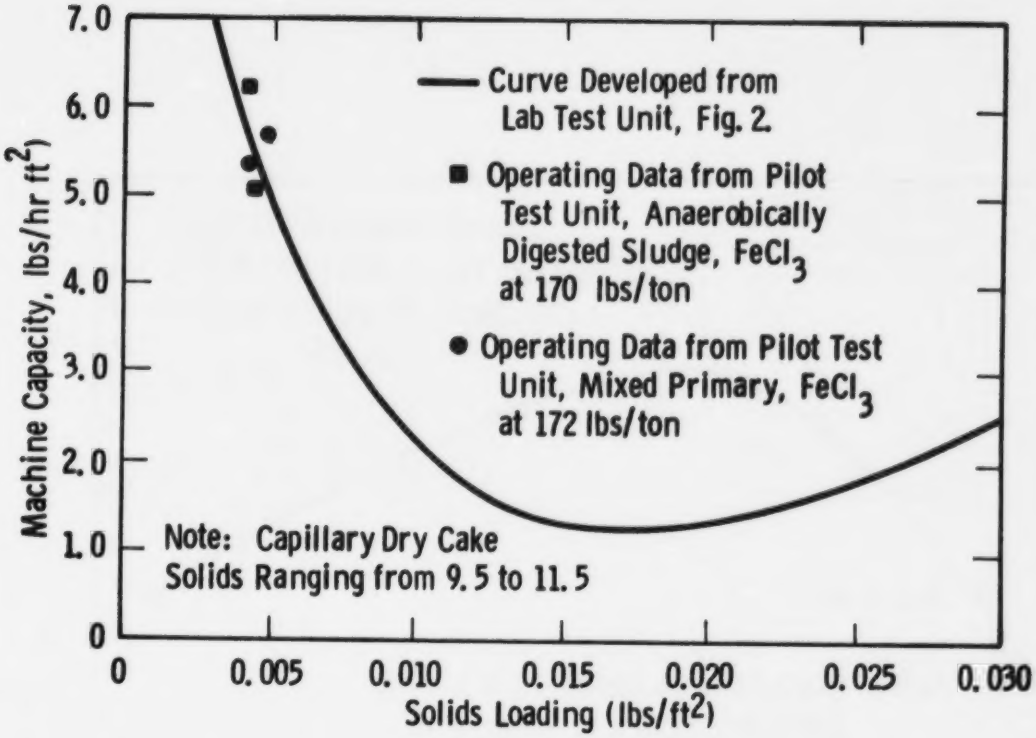


Fig. 15—Capillary dewatering - comparison of digested and mixed sludge data with design curve for wasted activated sludge

(Kgs/m^2 = 0.205 lbs/ft^2, Kgs/ton (m) = 2.0 lbs/ton)

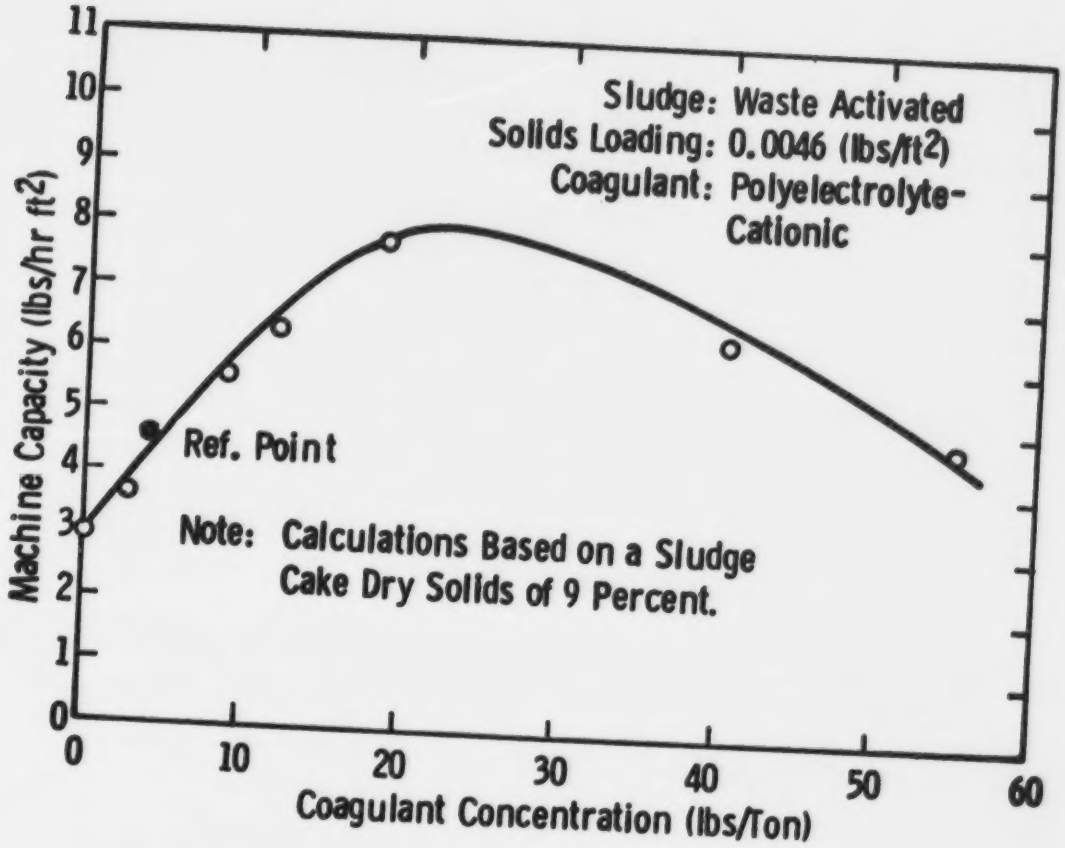


Fig. 16 – Capillary dewatering – calculated machine capacity (kgs/m^2 = 0.205 lbs/ft^2, kgs/ton(m) = 2.0 lbs/ton)

a decrease in coagulant concentration from 4 lbs/ton (2 Kg/metric ton) to zero decreases machine capacity to 3.0 lbs/hr ft^2 (15 Kgs/hr m^2).

Similar data obtained in a second series of tests would indicate that an even more dramatic increase in machine capacity can be realized by increasing coagulant dosages. Capacities more than twice those suggested by the data in Figure 16 were calculated i.e., capacities as high as 20 lbs/hr ft^2 (100 Kgs/hr m^2). In this second case, the basis for the calculation was an 8 percent cake at the end of the capillary section. This calculated data is shown in Figure 17 for both the use of polyelectrolyte and ferric chloride. It must be cautioned that the calculated quantities are based on sludge samples taken along the length of the capillary zone. Because of the expontial nature of the sludge drying curves (see Figure 13) relatively small discrepancies in the cake solids near the equilibrium value can represent large incremental changes in the equivalent length of the capillary zone. This length value figures directly into the capacity calculation. Actual operating data at these high capacities is needed to verify the calculations.

A similar trend with coagulant dosage and machine capacity was obtained for the mixed primary and the digested sludges, Figures 18 and 19. In these cases a maximum four fold increase in machine capacity was calculated.

All of the above data were obtained for a relatively low solids loading. The effect of coagulant dosage on capacity at a higher solids loading is unknown. Thus, data at other sludge solids loadings with and without chemical additions is needed to determine how these curves are affected. This information would provide then a more comprehensive basis to optimize machine capacity. Furthermore, it remains to be determined if the reduced capital cost realized by doubling the machine capacity with large coagulant addition exceeds the higher chemical costs.

The behavior of machine capacity with coagulant concentration is not unlike that observed with the sludge's specific resistance (a measure of sludge dewaterability). During the course of this investigation, the specific resistance measurements were made for each sludge type and the data are presented in Figures 8, 9, and 10. The data for the mixed primary and the digested sludges were obtained after the sludges had been conditioned with a polyelectrolyte coagulant. As can be learned from the figures, increasing the coagulant concentration improved dewaterability in each case i.e., decreased specific resistance. This suggests then, that the data reported in Figures 17, 18, and 19 can be combined using specific resistance as a normalizing parameter. Such a correlation was made for activated sludge using the data obtained for both the C-31 polyelectrolyte and the ferric chloride i.e., the data from Figure 17. The results are shown in Figure 20 where the machine capacity (lbs/hr ft^2) is plotted against sludge specific resistance. Based on the limited data obtained, it appears that machine capacity can be directly related to sludge specific resistance for learning the effect of increasing coagulant dosages. A similar comparison for the other two sludge types could not be made, since specific resistance values were not determined for the use of ferric chloride with these sludges.

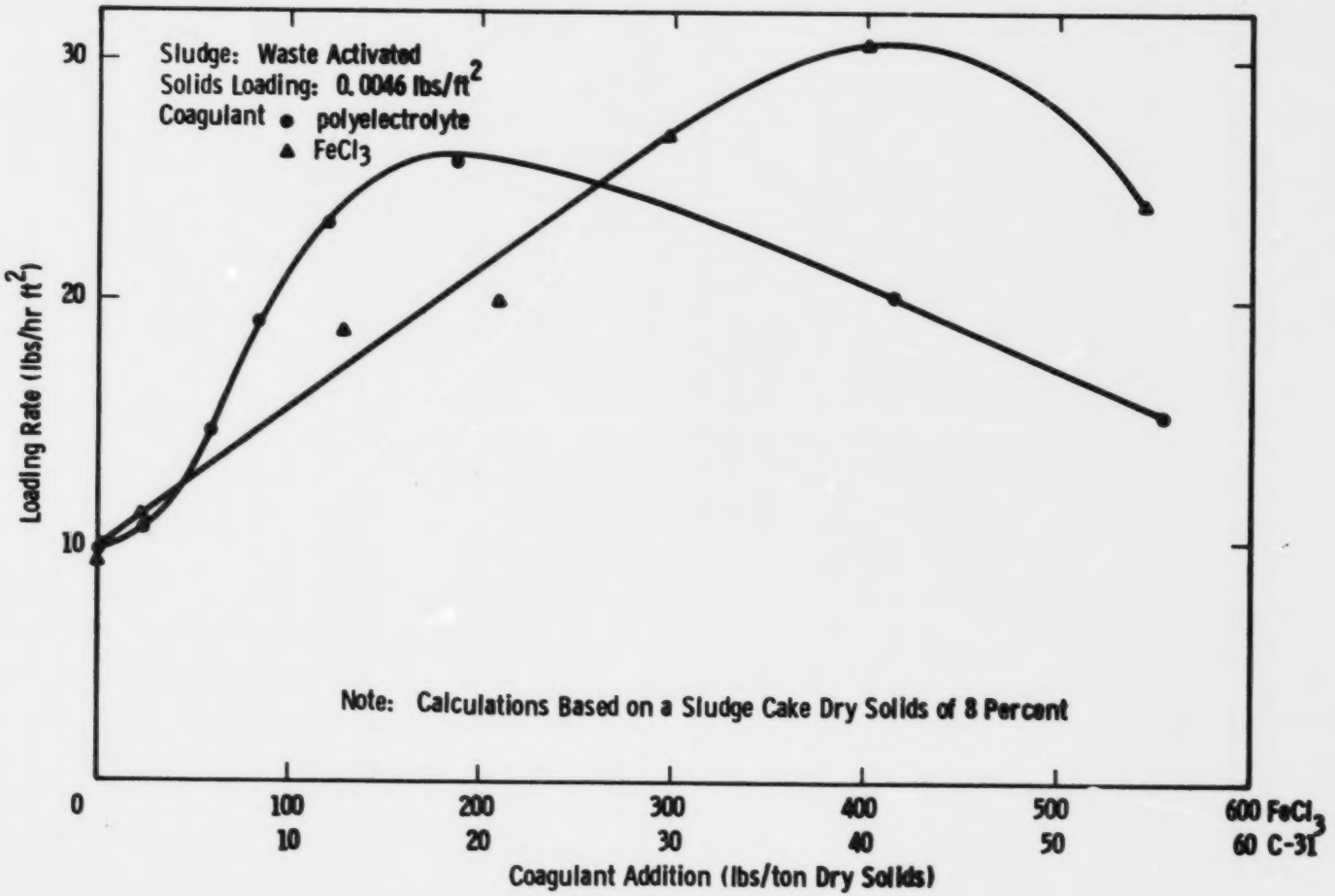


Fig. 17—Capillary dewatering - calculated machine capacity
(Kgs/m² = 0.205 lbs/ft², Kgs/ton(m) = 2.0 lbs/ton)

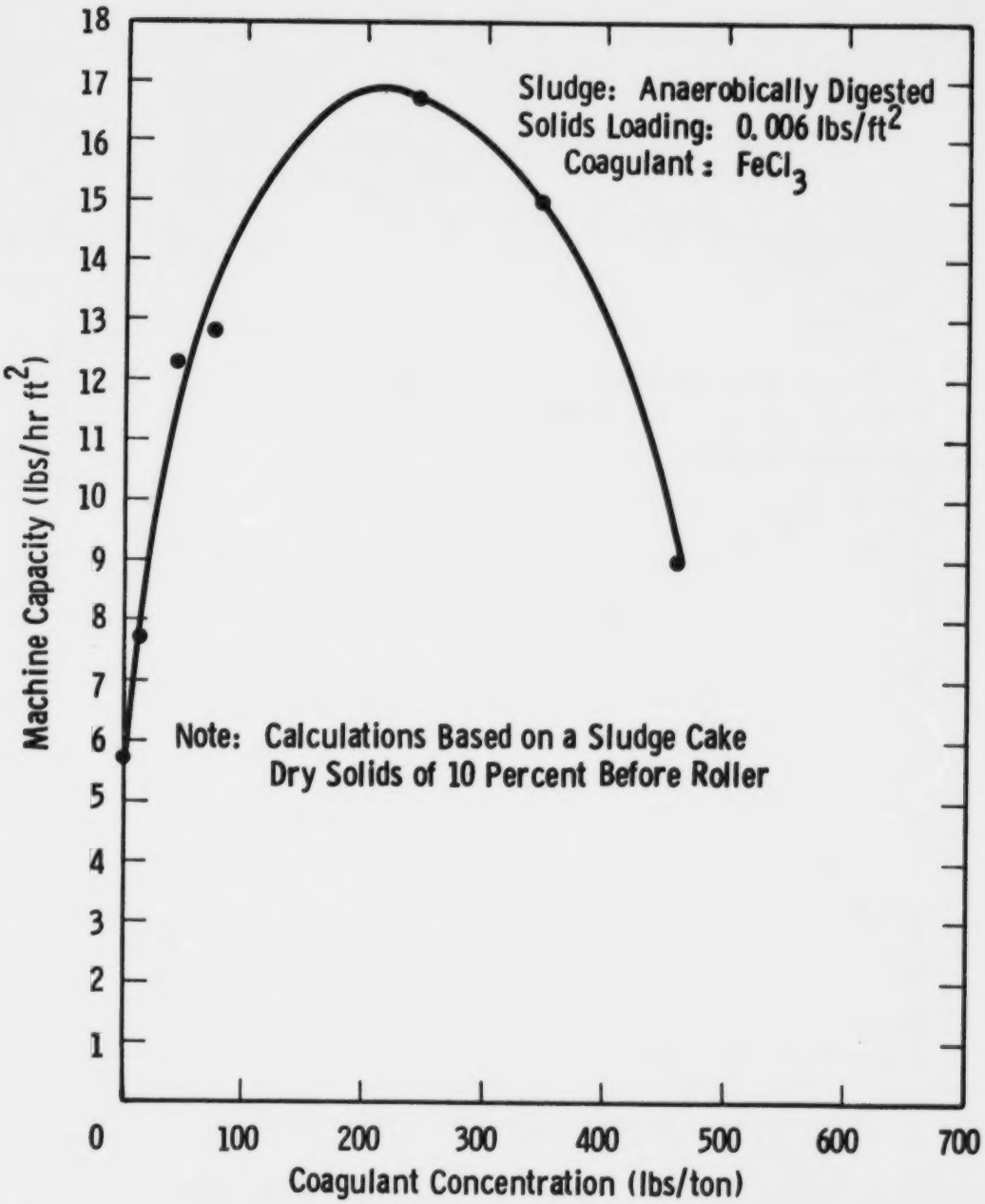


Fig. 18—Capillary dewatering - calculated machine capacity
(Kgs/m^2 = 0.205 lbs/ft^2, Kgs/ton (m) = 2.0 lbs/ton)

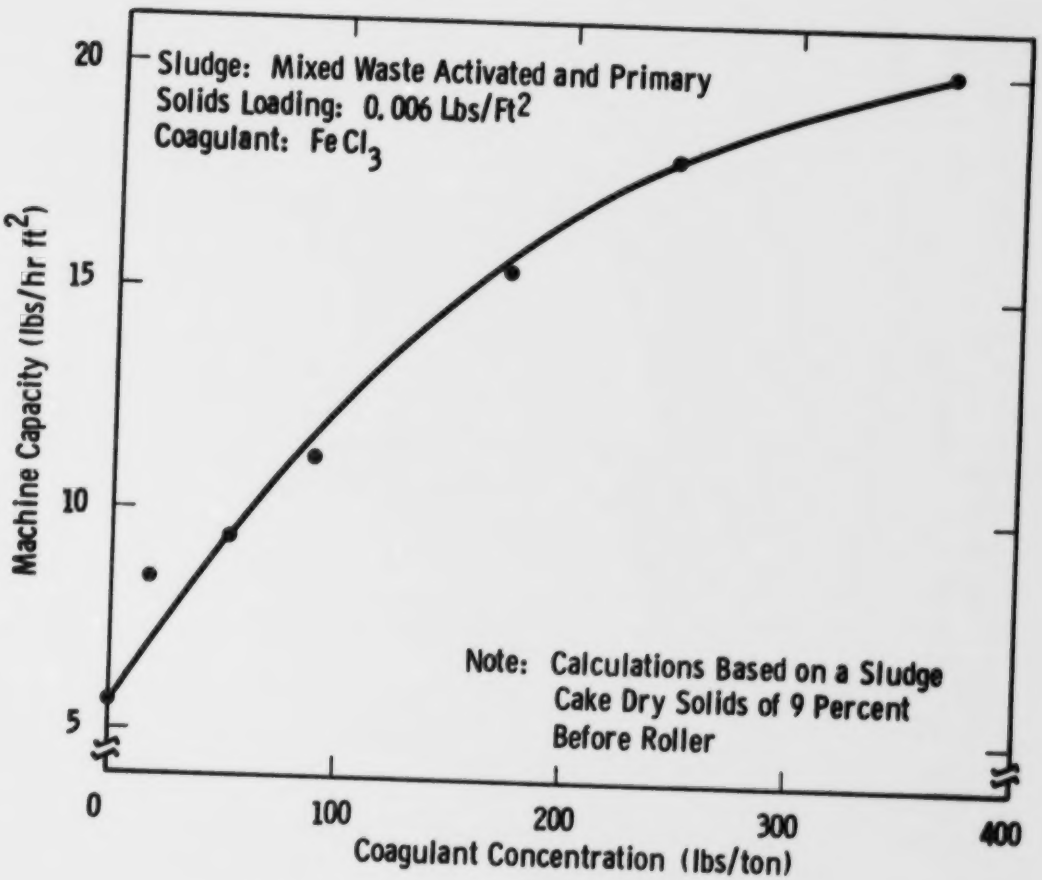


Fig. 19—Capillary dewatering - Calculated machine capacity
($Kgs/m^2 = 0.205$ lbs/ft^2, Kgs/ton (m) = 2.0 lbs/ton)

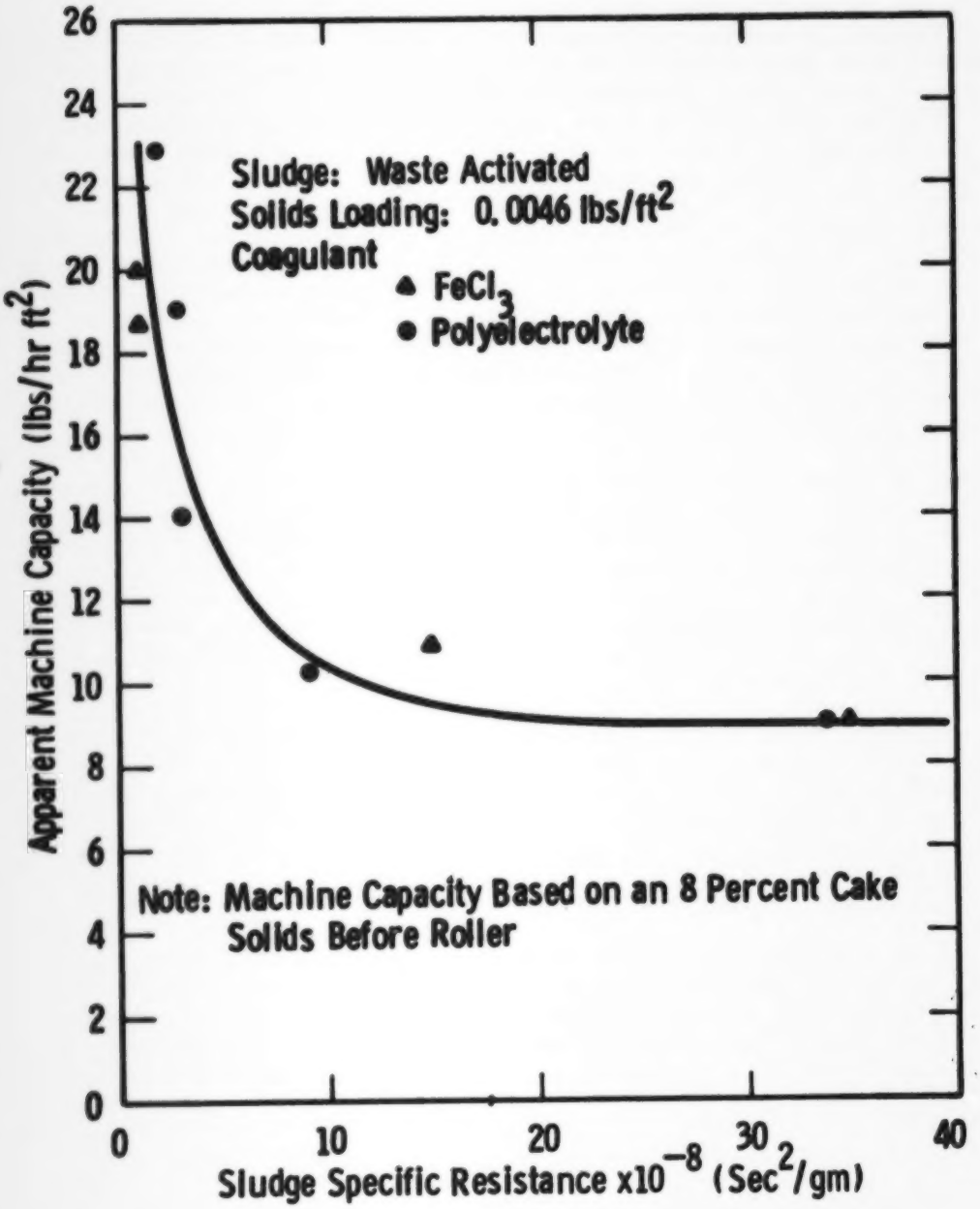


Fig. 20—Correlation of machine apparent capacity with sludge specific resistance for two coagulant types

($Kgs/m^2 = 0.205\ lbs/ft^2$)

A second consideration in the design of the capillary section is selection of the porous belt material. One parameter that was expected to affect cake dewatering is the belt average pore size. Decreasing belt pore size theoretically increases the capillary pressure and therefore produces a dryer sludge cake. Experiments were conducted to simulate the capillary dewatering section using sintered metal plates in which the pore sizes could be accurately controlled. The test apparatus is shown in Figure 21. Five such plates were tested corresponding to pore sizes of 1/2μ, 5μ, 10μ, 40μ and 100μ (μ= micron). These results are shown by the solid curve in Figure 22 where the sludge cake solids after 2.0 minutes dewatering (sufficient time to attain the final equilibrium) are plotted against pore diameter. The data is for a fixed sludge solids loading. The curve shows that final cake solids increased with decreased pore sizes, as expected, as long as the pores were above a 10μ size. Below 10μ, however, final cake solids decreased markedly. At these lower pore sizes, surface effects apparently inhibited wetting of the pore spaces and the capillary action was diminished. Thus, there is an optimum pore size (about 10μ) for obtaining maximum cake solids. This maximum was about a 12 percent cake for the particular solids loading indicated.

In addition to the sintered metal plate data, data from three other porous media materials are included in Figure 22. This data falls in line with the porous plate results. In view of the only slight improvement in sludge cake solids with the denser porous media and since an 8 percent cake at the end of the capillary section is satisfactory for machine operation, pore size alone is not an overriding consideration in specifying belt requirements. Pore sizes of 10μ or greater are adequate. It should also be noted that denser porous material (smaller pore size) costs more.

A third consideration in designing the capillary section is belt material integrity i.e., belt life. Two factors have been considered; (1) belt structural strength and (2) belt biological stability. The mechanical tensile strength of the porous belt is maintained by inlaying a "scrim" (a reinforcing plastic or cloth screen) along the length of the belt. Figure 23 shows a photograph of one felt porous belt and reinforcing scrim. This scrim serves as the load carrying member and will tolerate tension loads as high as 2500 psi without failing.

To evaluate the biological stability of various porous belt materials, swatch samples of these belt materials were attached to the tracking belt of the life test unit (Fig. 11) and allowed to interact with activated sludge. A small mechanical compression load was also applied to each swatch sample in an attempt to simulate the mechanical-biological interactions that would occur in the operation of the capillary dewatering machine. Five different basic types of porous materials were initially selected for evaluation. They were polypropylene felt, wool felt, polyurethane foam, dacron felt and a rayon viscose felt. Several grades of the different felts and foam were tested, totaling some 15 swatch samples altogether. A photograph of the five basic porous material types before testing began and after 30 days is shown in Figure 24. Shortly after the first 30 days, both the rayon viscose and wool felts were destroyed i.e., completely fell apart. At this time, a nylon felt was substituted. A pictorical history of the remaining swatch samples is given in Figs. 25 and 26 which show

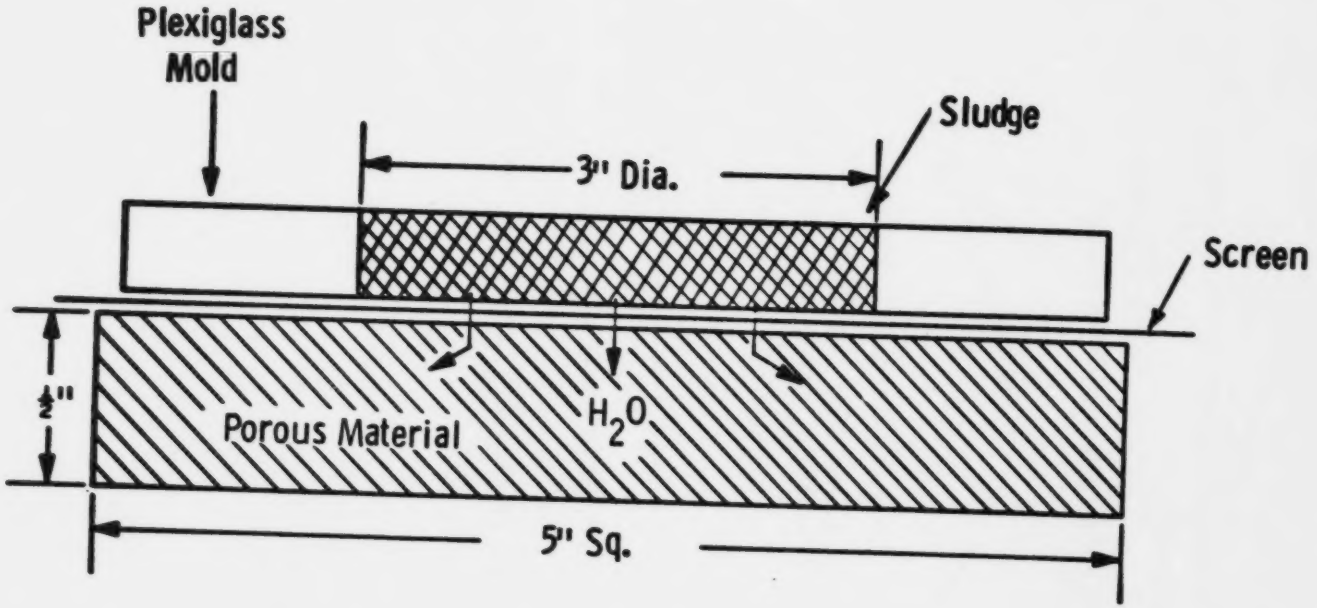


Fig. 21– Schematic arrangement of swatch test apparatus for simulating capillary dewatering (cm = 0.3937 in)

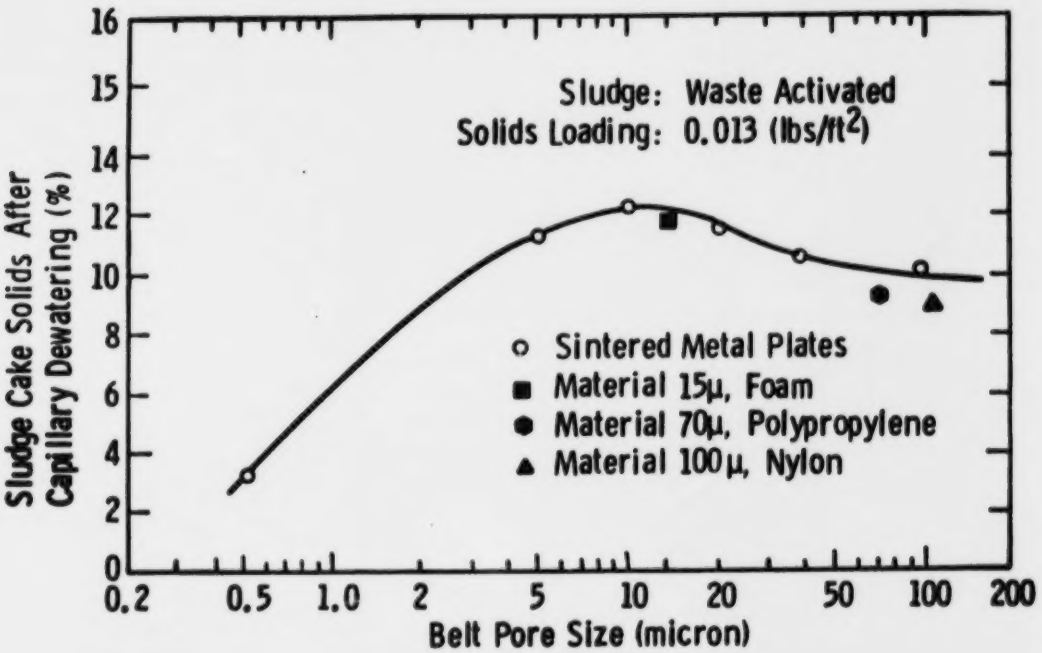


Fig. 22 — Belt pore size effect on capillary dewatering cake solids
(kgs/m^2 = 0.205 lbs/ft^2)

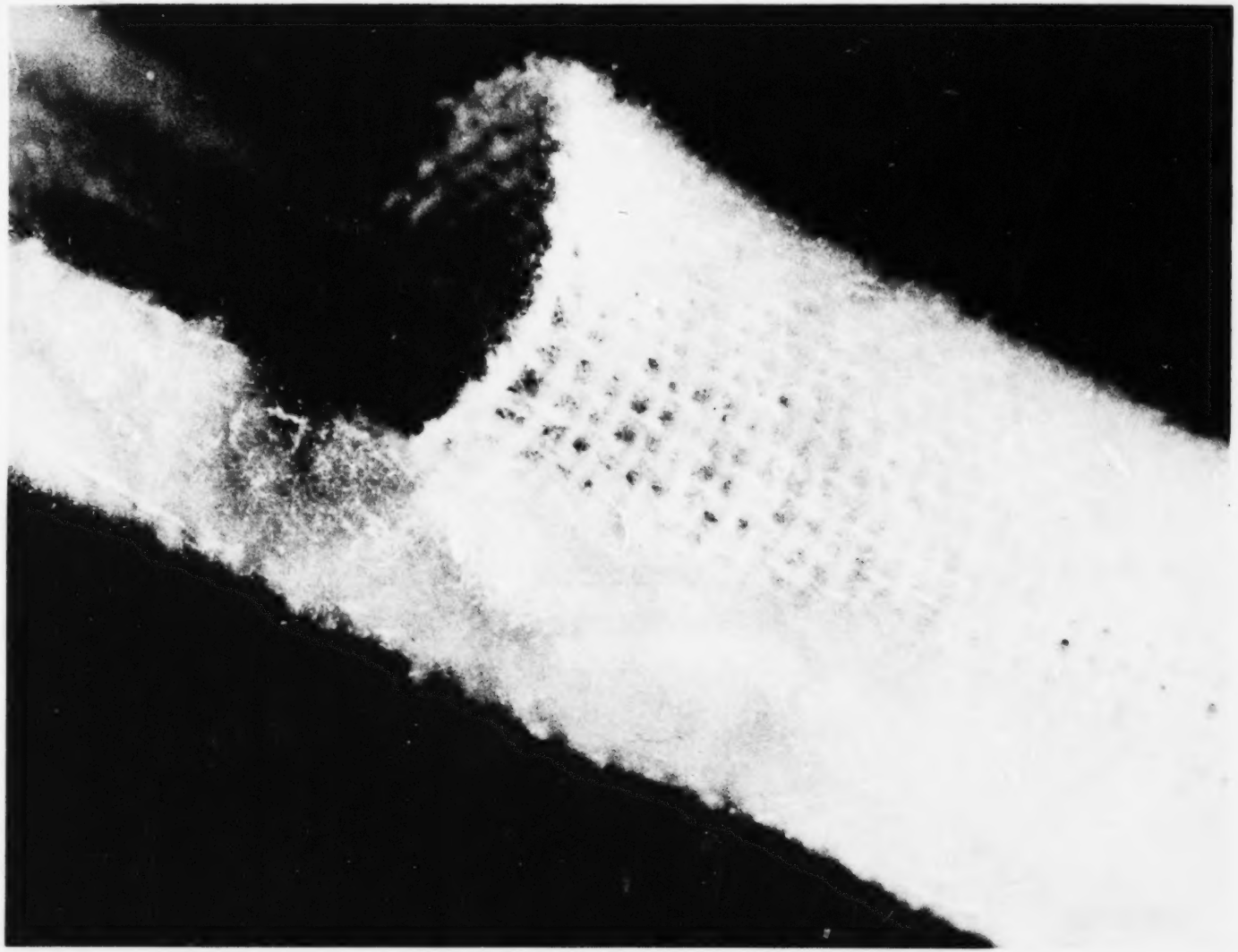


Fig. 23 - Porous felt and reinforcing scrim.

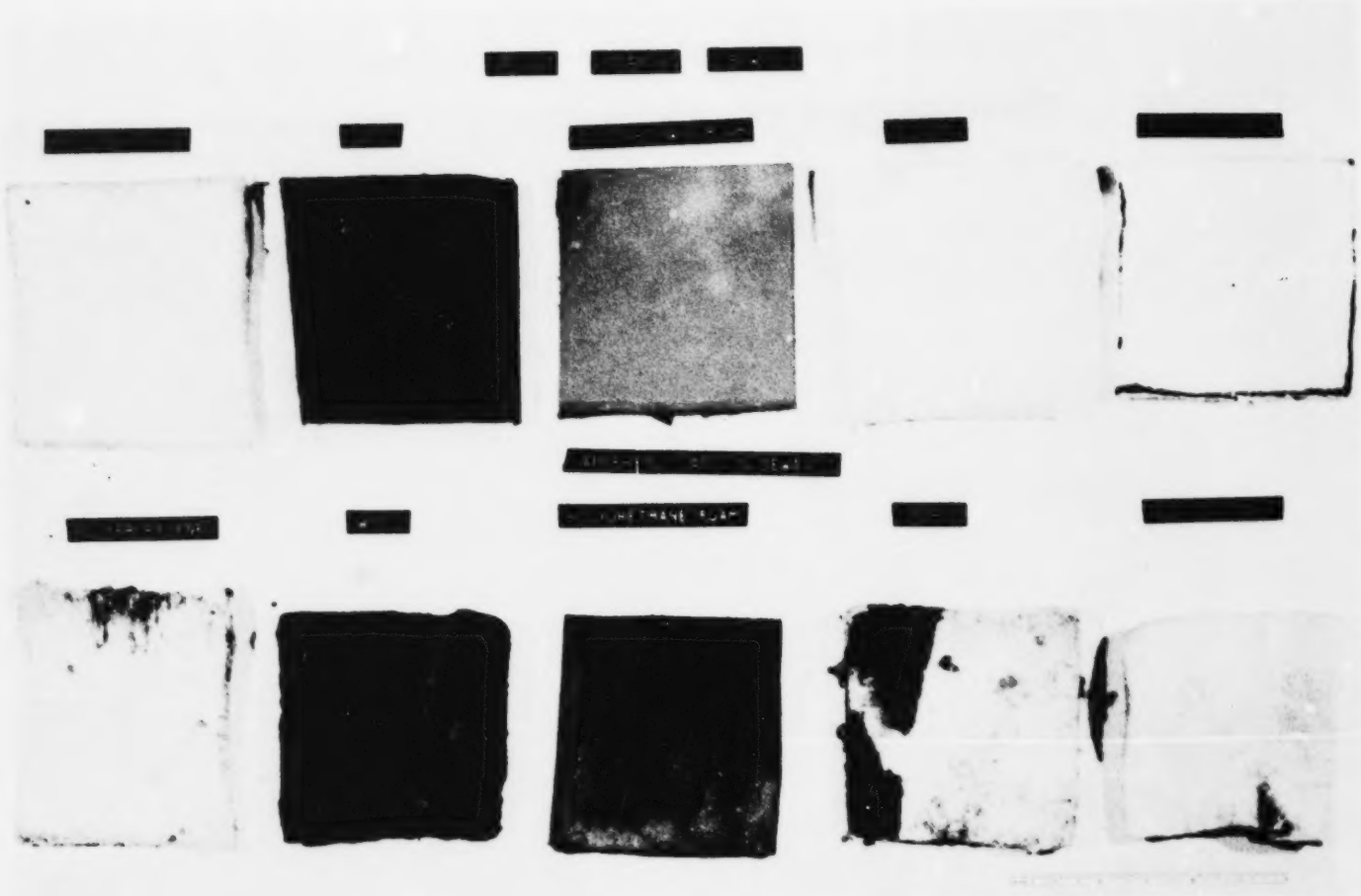


Fig. 24 - Five basic porous material swatch samples before and after 30 days testing.

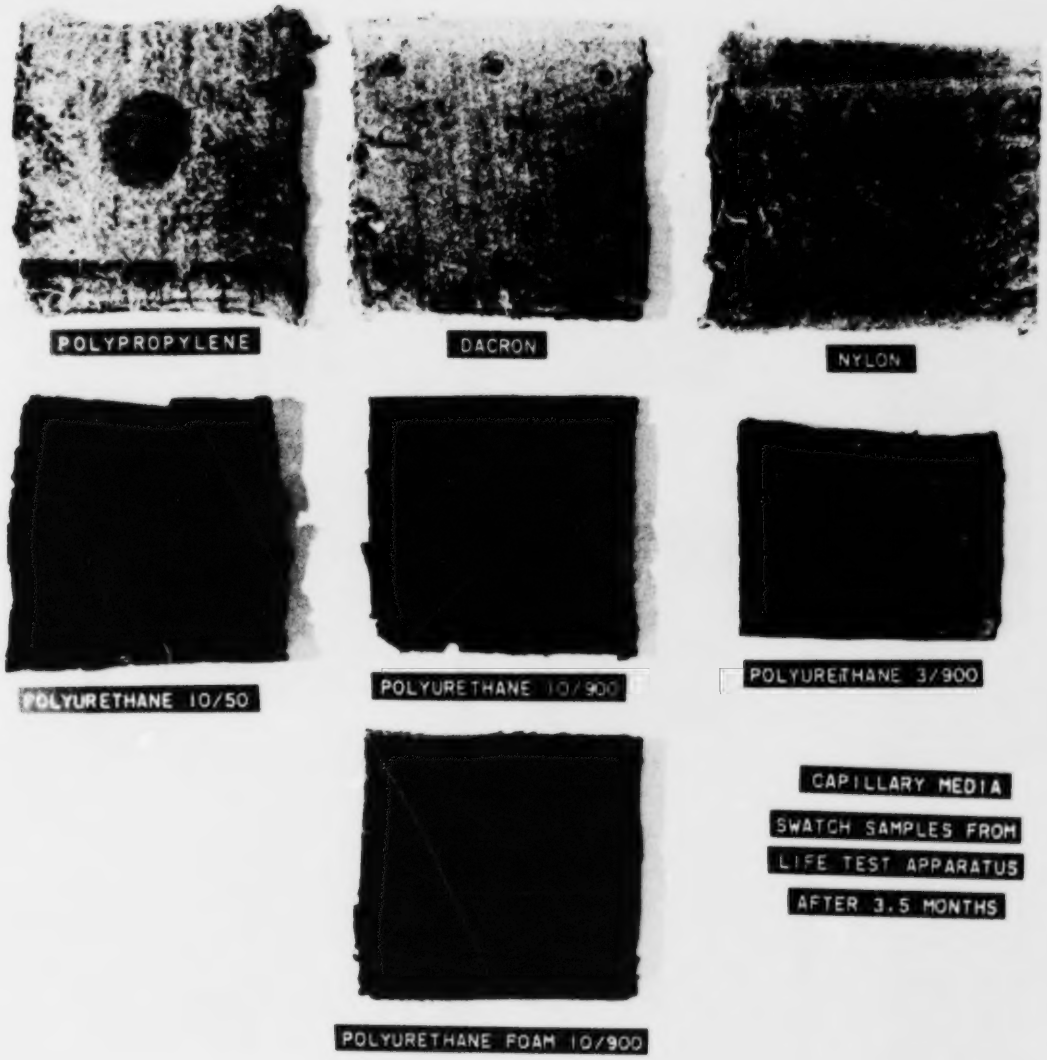


Fig. 25 - Swatch samples after 3.5 months.

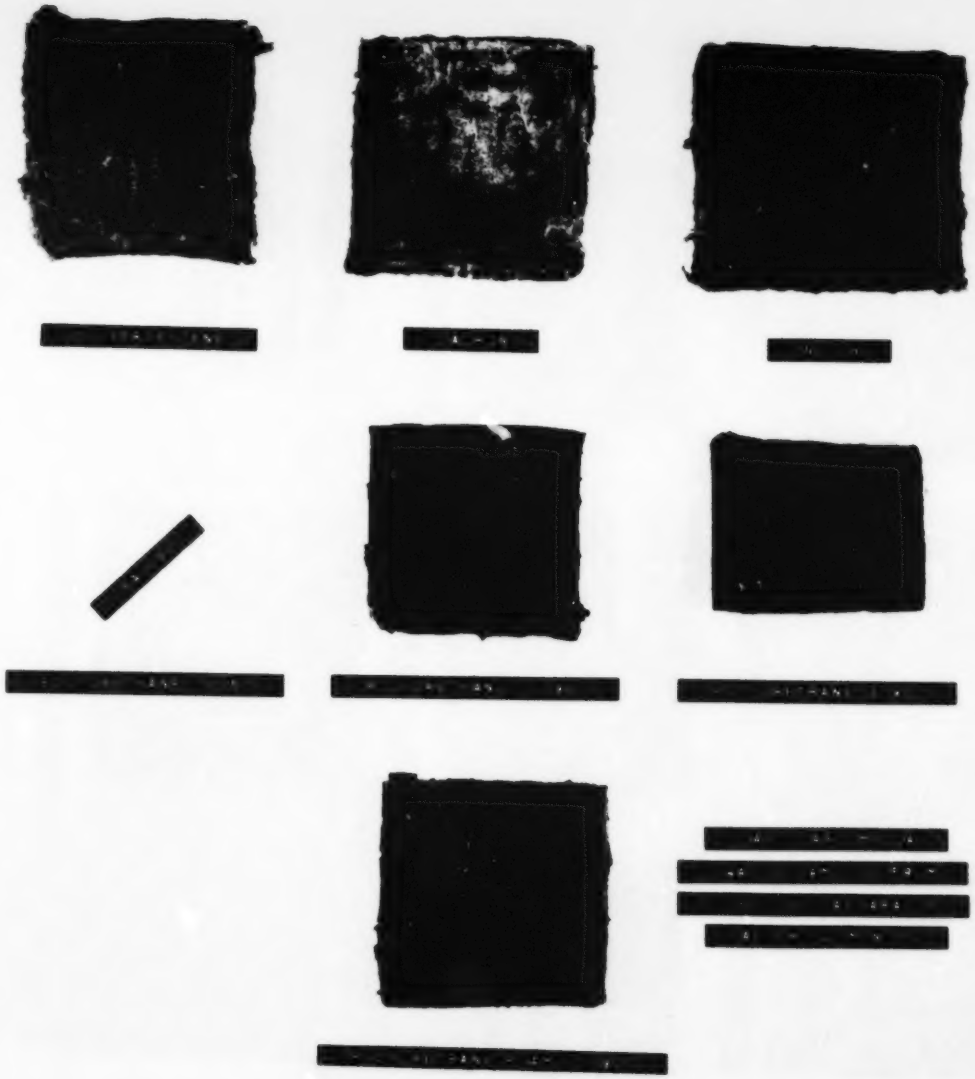


Fig. 26 - Swatch samples after 12 months.

the samples after 3 1/2 and 12 months testing, respectively. The three felt materials appear in reasonable shape even after 12 months but the foams would probably not be acceptable for use. Capillary dewatering tests after 3 1/2 and 12 months and a strength test (tension) after 12 months were performed on each sample. Results of the dewatering tests were inconclusive but the data showed that each of the swatch samples including the foams retained a wicking capability even after 12 months of testing in the life unit. It is probable that 12 months exposure in the life test unit corresponds to about 24 months of equivalent operating time on the actual dewatering device. This extrapolation is based simply on the number of cycles per day the life test apparatus imposes on each sample in comparison to the cycles per day demanded by the dewatering unit.

Results of the tension test done on both new and used belt samples (after 12 1/2 months in life test unit) are given in Table 5 below.

Table 5

Material	Tensile strength (ultimate) (psi) New	12 1/2 mo.	% of Original strength
Polypropylene	2500	800	32
Nylon	1440	1200	84
Dacron	1600	1000	62
Polyurethane	75	65	86

It should be noted that tensile strength measured reflects that of the scrim support and not that of the belt material. The polyurethane had no scrim support. The scrim materials used for the polypropylene and Dacron felt materials are uncertain but believed to be polyester. The nylon material used a nylon scrim.

In addition to the life test evaluations, periodic examinations were made of the porous belt used on the pilot test unit. Figure 27 shows a photograph taken of the belt after 12 months of testing with the pilot unit (approximately 300 hrs of actual test hours). Some surface abrasion has occurred as evident by the partial unstranding of the fibers. This has not deterred machine operation. Some discoloration is also noted. Based on this study, it would appear that the porous felt belt materials should endure at least one year operation.

COMPRESSION ROLLER DESIGN - FINAL CAKE SOLIDS

The function of the compression roller is to: (1) increase sludge solids from 8 percent to over 16 percent and (2) detach the sludge from the screen belt. Sludge solids loading (solid weight/unit area) and compression roller force (force/unit width of belt) are two parameters found to influence final sludge cake solids. These effects were measured in separate tests using the small lab unit where the actual roller compression force was directly measured with a strain gauge. These tests were done with the waste activated sludge. Similar

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Fig. 27 - Photograph of porous belt from pilot unit after 12 months of testing.

data was also obtained from the pilot test unit using all three sludge types. In this case the magnitude of the roller compression force was determined by measuring the spring deflection (the springs to which the roller is mounted).

It was found that cake solids increased when the compression force was increased and increased when the solids loading (cake thickness) was decreased. The normal force load range studies corresponded to approximately a 15 to 45 psi average (1-3 atm). A third parametric effect was also identified which corresponds to the time of contact between the sludge and compression roller. This sludge contact time is directly related to the linear belt speed, roller diameter and wrap angle between the belt and compression roller i.e.,

$$t_{eff} = \frac{r\theta}{V_b}$$

where t_{eff} = contact time between the sludge and roller during compression

r = radius of the roller

θ = wrap angle

V_b = linear belt velocity

It was found that by increasing t_{eff} (keeping solids loading and compression force constant) a dryer cake was produced. Combining the three parameters according to the observed experimental effect, a roller compression parameter was formulated that adequately correlates the data. The parameter is given by $[F \cdot t_{eff}/S.L.]$ where F is the roller compression force in lbs/in, S.L. is the sludge solids loading in lbs/ft^2 and t_{eff} is in seconds.

The correlation established between cake solids and the roller compression parameter is shown in Figure 28. In each case, the wrap angle θ was taken as 20° on the lab unit and 10° on the pilot unit.

The data for the activated sludge suggests that an approximately linear relationship exists between final cake solids and the roller compression parameter over the range of the test data. Increasing the compression parameter from 100 to 400 increased cake solids from 14 to 20 percent.

The two single data points shown for the anaerobically digested sludge suggests that the correlation developed for the activated sludge is not applicable to this sludge. Only one data point is available for the mixed sludge and that falls close to the activated sludge data. This would not be totally unexpected since the greater quantity of the mixed sludge is the waste activated sludge.

One factor which is not accounted for in the compression roller parameter grouping is that of coagulant dosage. This effect is shown separately for each sludge type in Figure 29. The data shows that for each sludge type even a marginal addition of coagulant will increase the final cake solids. For example, with the digested sludge, adding 1 percent (based on dry solids weight) coagulant the final cake solids was increased from 13.4 (zero coagulant) to 14.8 percent. However, addition of still more coagulant does not appear to produce a proportionate increase in cake solids. Thus, the effect on cake solids of addition coagulant appears to be significant only at the lower dosage concentrations.

△: Pilot Test Unit, Fig. 3
Waste Activated Sludge, Polyelectrolyte at 4.0 lbs/ton

○: Lab Test Unit, Fig. 2
Waste Activated Sludge, Polyelectrolyte at 4.0 lbs/ton

▲: Pilot Test Unit, Mixed
Activated - Primary Sludge, $FeCl_3$ at 172 lbs/ton

■: Pilot Test Unit, Anaerobically Digested Sludge,
$FeCl_3$ at 170 lbs/ton

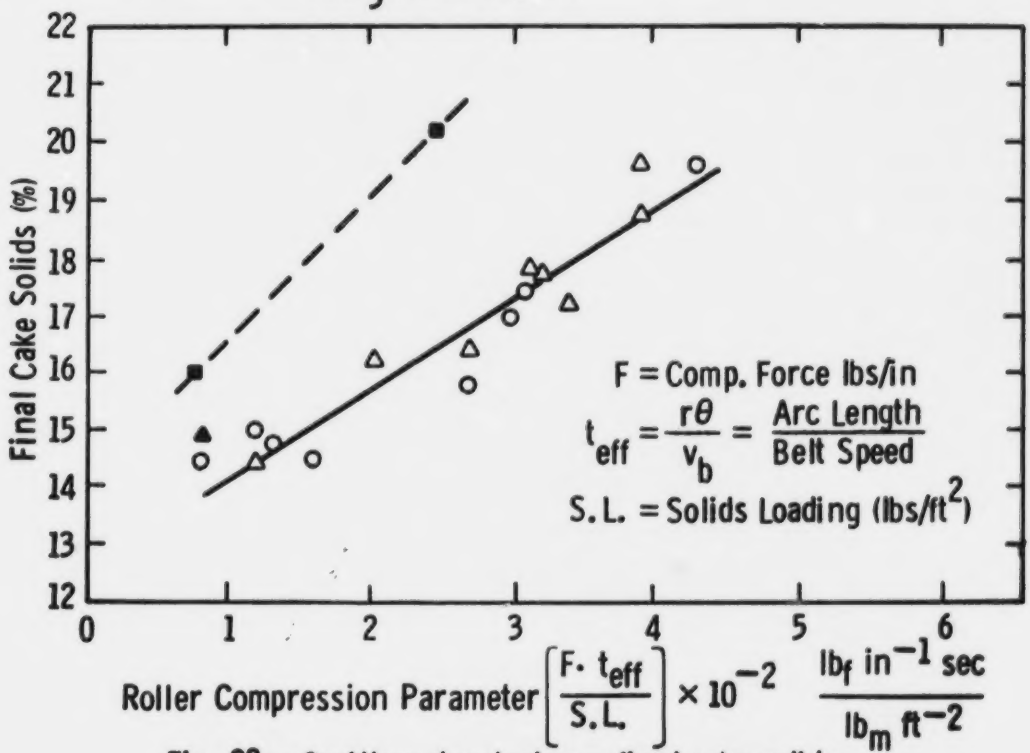

Fig. 28 – Capillary dewatering – final cake solids
(kgs/m^2 = 0.205 lbs/ft^2, kgs/ton = 2.0 lbs/ton)
(kg/m = .056 lbs/in)

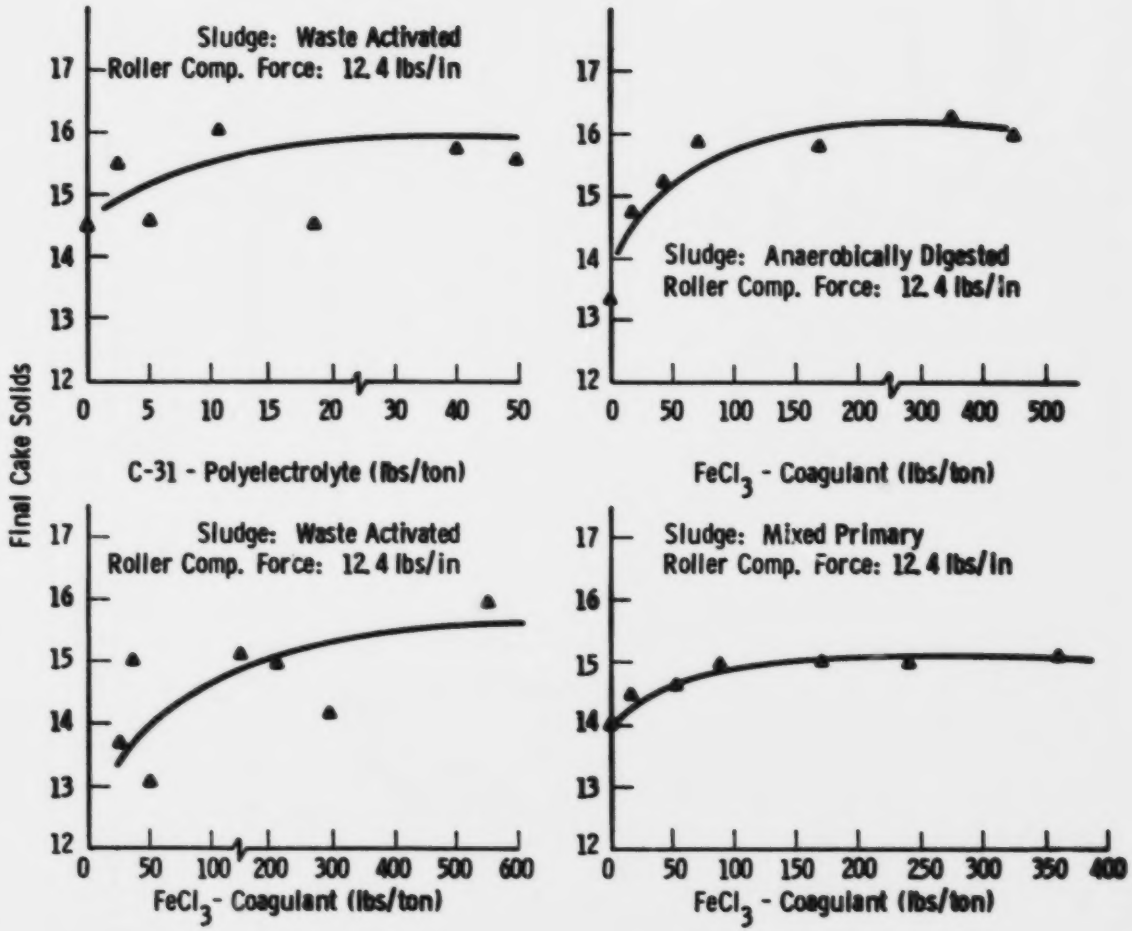

Fig. 29—Effect of coagulant dosage on final cake solids
($Kgs/m^2 = 0.205\ lbs/ft^2$, Kgs/ton (m) = 2.0 lbs/ton)

The significance of the compression roller parameter, aside from correlating the data from both test units, is that it provides a design "tie-in" with the capillary section. Both the solids loading (S.L.) and belt speed are specified from design considerations of the capillary section. This leaves only the roller diameter and compression force to be specified in designing the roller compression section to achieve the desired final cake solids.

A further consideration in the operation of the roller compression section involves the preferential adherence of the sludge to the roller. A photograph depicting this sludge cake detachment is shown in Figure 30. Excessive roller compression force and sludge over-coagulation with polyelectrolyte were found to adversely effect sludge cake detachment. High compression forces forced the sludge solids into the screen decreasing solids capture. With the higher polyelectrolyte coagulant dosages, the sludge attained a "tacky" (or slippery) appearance, and the sludge cake would not adhere to the compression roller surface. Other factors that could effect cake detachment include screen material, weave, and fiber diameter. These parameters have not been evaluated in this program.

SLUDGE CAKE SOLIDS CAPTURE

Present practice in sewage sludge dewatering is to normally recycle the process filtrate back to the head end of the treatment plant. Thus, high filtrate quality (low BOD, solids, etc.) is not generally demanded. However, sufficiently good solids capture ($\sim$85%) is required to avoid the problems associated with continued recirculation of fine solids. Ultimately these problems can lead to deterioration of filter production and inceased chemical conditioning requirements.

In the capillary dewatering system, to obtain high solids capture, the sludge solids must not pass through the screen belt. Solids passage is controlled by screen mesh size, sludge floc size, and roller normal force. The first two parameters were studied in separate experiments.

The effect of screen mesh size (screen opening) is illustrated by the data shown in Figure 31. Four different size screens (100, 200, 325, and 400 mesh) were evaluated using the swatch test apparatus shown in Figure 31. Each screen was evaluated by measuring the weight fraction of solids that escaped the respective screens when the sludge was applied. These tests were conducted with waste activated sludge applied at a relatively heavy solids loading (0.080 lbs/ft^2) (0.34 Kgs/m^2) and conditioned with 4.0 lbs/ton (2.0 Kg/metric ton) polyelectrolyte. As the data shows, increasing screen mesh size (decreasing screen opening) improves solids capture. This is particularly evident at the higher mesh sizes. Above 300 mesh, however, there appears to be very little additional improvement in solids capture with further increases in screen mesh.

Solids capture data was also obtained while operating the pilot test unit with activated sludge. This data was taken with machine capacities ranging from 2.0 to 4.6 lbs/hr ft^2 (10 to 22 Kgs/hr m^2); coagulant dosages from 0 to over 40 lbs/ton (0 to 20 Kgs/metric ton) of a polyelectrolyte; and two different mesh screens (200 and 300 mesh). The data is given in Figure 32, which shows sludge cake

Fig. 30 - Photograph depicting sludge cake detachment.

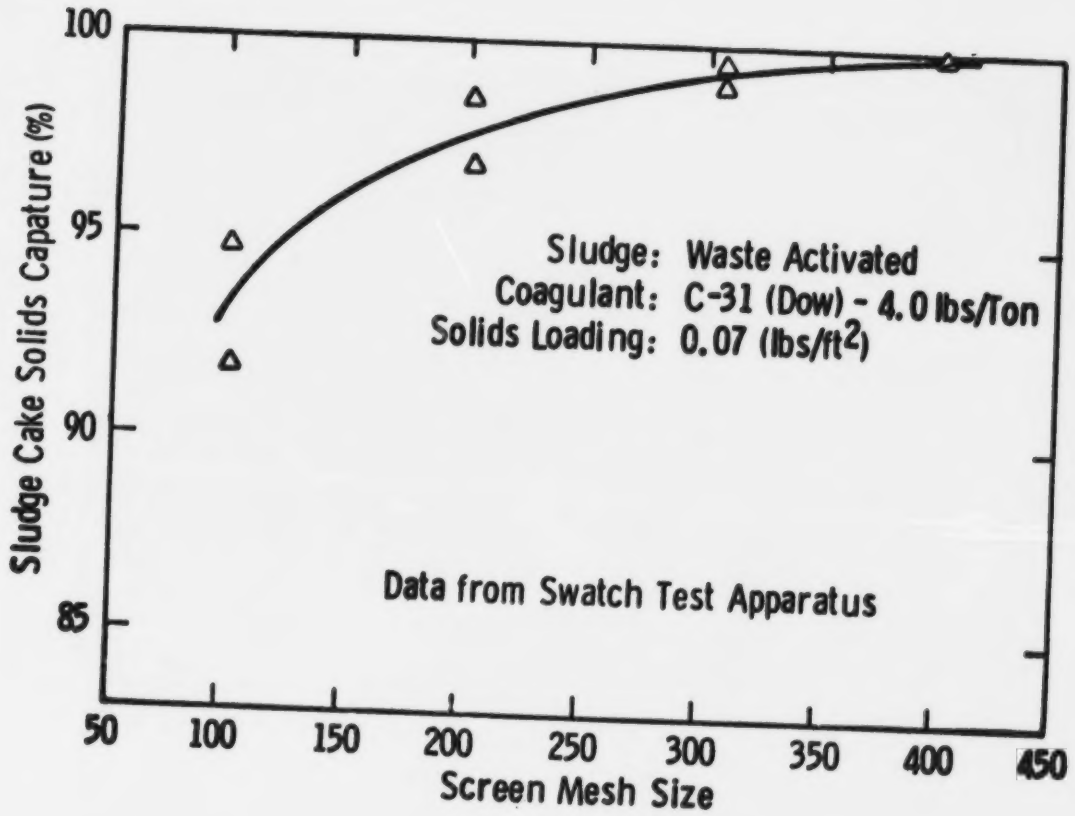

Fig. 31 – Effect of screen mesh size on solids capture
($kgs/m^2 = 0.205\ lbs/ft^2$, kgs/ton(m) = 2.0 lbs/ton)

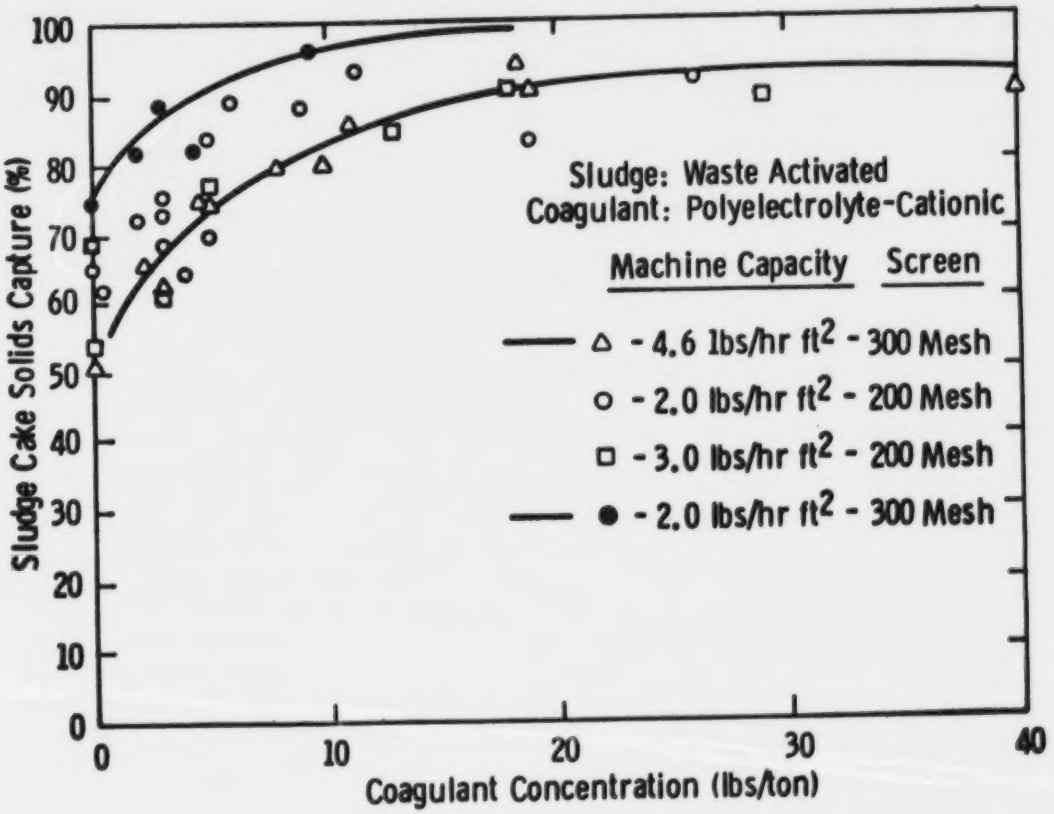

Fig. 32 – Capillary dewatering – sludge cake solids capture
(kgs/m^2 = 0.205 lbs/ft^2, kgs/ton(m) = 2.0 lbs/ton)

solids capture as a function of coagulant dosage under various operating conditions. The data is for the polyelectrolyte coagulant only. The effect of screen mesh size is as previously predicted in Figure 31.

The improved cake capture with increased coagulant addition is as expected. With no coagulant addition, cake capture varied from 50 to 75 percent depending on the machine feed rate and screen type. Cake solids captures of 95 percent or higher were achieved at a coagulant dosage of 10 lbs/ton (5 Kgs/metric ton) or about $4.00/ton ($4.40/metric ton) dry solids. This is at a machine capacity of 2.0 lbs/hr ft^2 (10 Kgs/hr m^2). Increasing machine capacity to 4.6 lbs/hr ft^2 (22 Kgs/hr m^2) by reducing the solids loading (i.e., maintaining a thinner cake but increasing the sludge pumping rate and belt speed) diminshed cake solids capture. This is attributed to the fact that a thinner sludge cake is not as effective in capturing fines as a thicker cake. Solids capture can be improved at the higher machine capabilities by increasing coagulant dosage. Thus, a trade-off between machine capacity, coagulant dosage and cake filtrate quality can be made.

The data showing cake solids capture for activated sludge with ferric chloride conditioner is shown in Figure 33. The data was taken with the 300 mesh screen at a machine capacity of 4.3 lbs/hr ft (21 Kgs/m^2 hr). Comparing this data with the equivalent data in Figure 32 shows that 90 percent solids capture is obtained at about a 15 lbs/ton (7.5 Kgs/metric ton) polyelectrolyte while the equivalent solids capture for the ferric chloride is obtained at 130 lbs/ton (65 Kgs/metric ton). On a cost basis, this means $6/ton ($6.60/metric ton) of dry sludge solids to condition with polymer and $5.20/ton (5.72/metric ton) to condition with ferric chloride ($FeCl_3$). On this basis, it must be reasoned that the ferric chloride is more cost effective than the polyelectrolyte. With the capillary dewatering system, this difference could be associated with the relative effectiveness of the two coagulants in effecting sludge cake detachment. The polyelectrolyte has an inherent tackiness which appears to inhibit cake detachment (cake tends to adhere to the screen belt). This consideration is in and above any differences in the coagulating effectiveness of the two conditioners. When comparing the two coagulant systems, these factors must be balanced against the larger volume of sludge produced due to the addition of significant amounts ferric chloride, the expense of handling the larger volumes of coagulant, and the corrosive nature of ferric chloride solutions. Lime may be added in the plant to control corrosion and improve conditioning.

Solids capture data for the anaerobically digested and mixed primary sludges are shown in Figures 34 and 35. With digested sludge, solids captures over 90 percent were attained at a coagulant dosage of 300 lbs/ton (150 Kgs/metric ton). This data is for a machine operating between 5 and 6 lbs/hr ft^2 (24-30 Kgs/m^2 hr). With the mixed primary sludge, the best solids capture achieved was 85 percent. This is a coagulant dosage of 250 lbs/ton (125 Kgs/metric ton). Both of these sets of data were attained using ferric chloride conditioner.

GENERAL MACHINE OPERATION

Operation of the capillary dewatering pilot scale test unit has provided sufficient experience to anticipate potential problems with a full scale system. The general operation of the unit on activated sludge was excellent. There were no particular

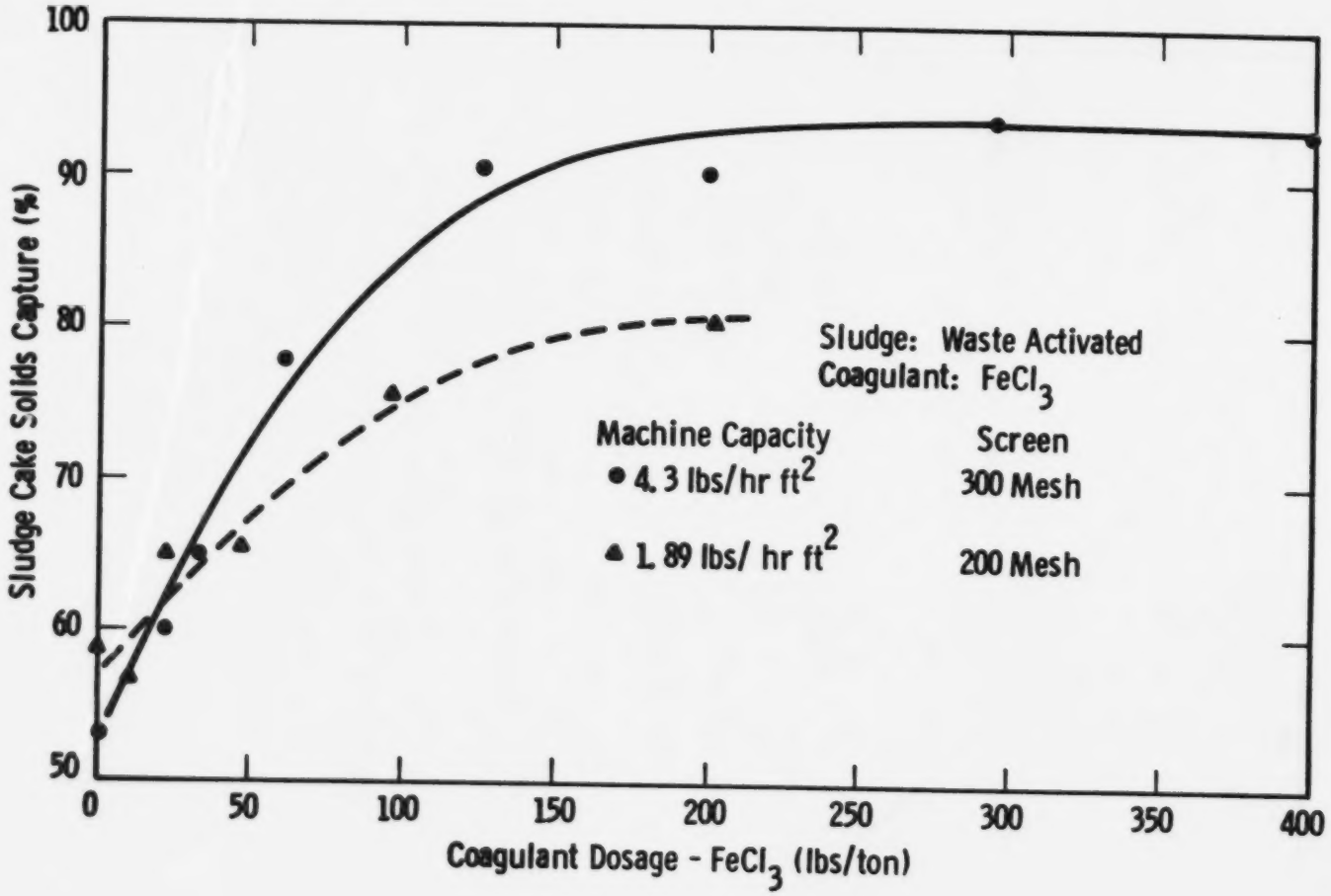

Fig. 33—Capillary dewatering - sludge cake solids capture
($Kgs/m^2 = 0.205$ lbs/ft^2, Kgs/ton (m) = 2.0 lbs/ton)

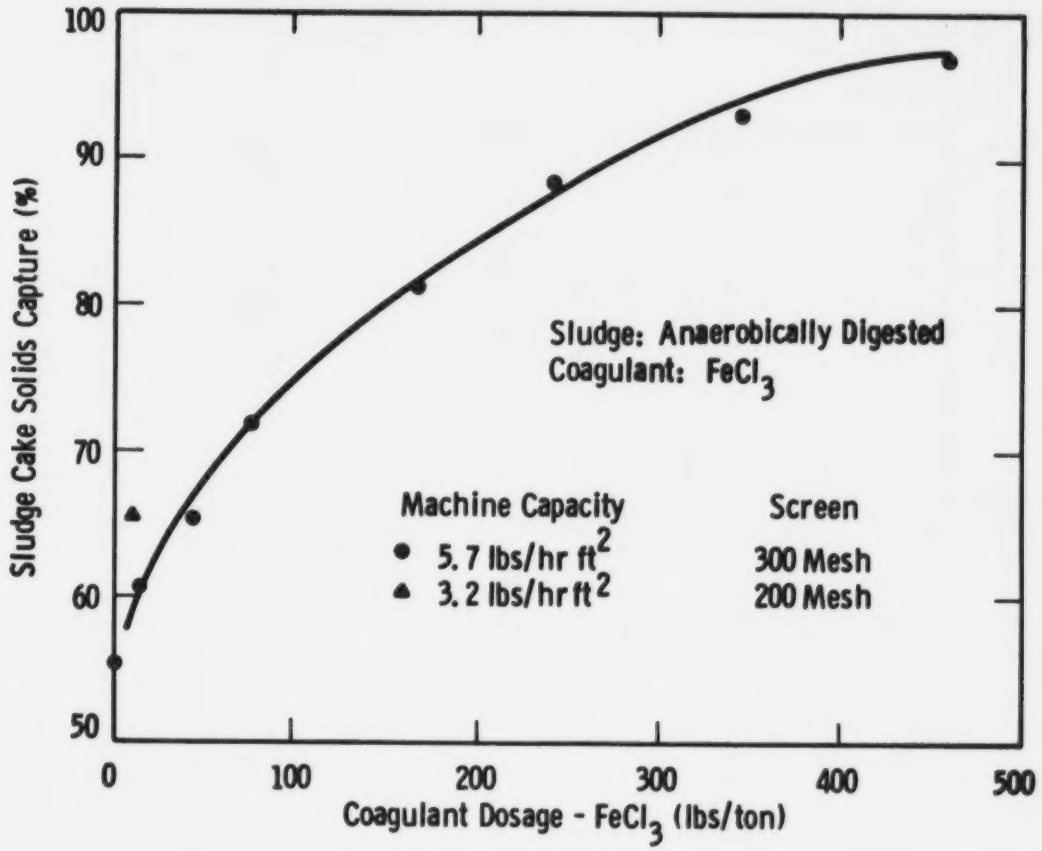

Fig. 34—Capillary dewatering - sludge cake solids capture
(Kgs/m^2 = 0.205 lbs/ft^2, Kgs/ton (m) = 2.0 lbs/ton)

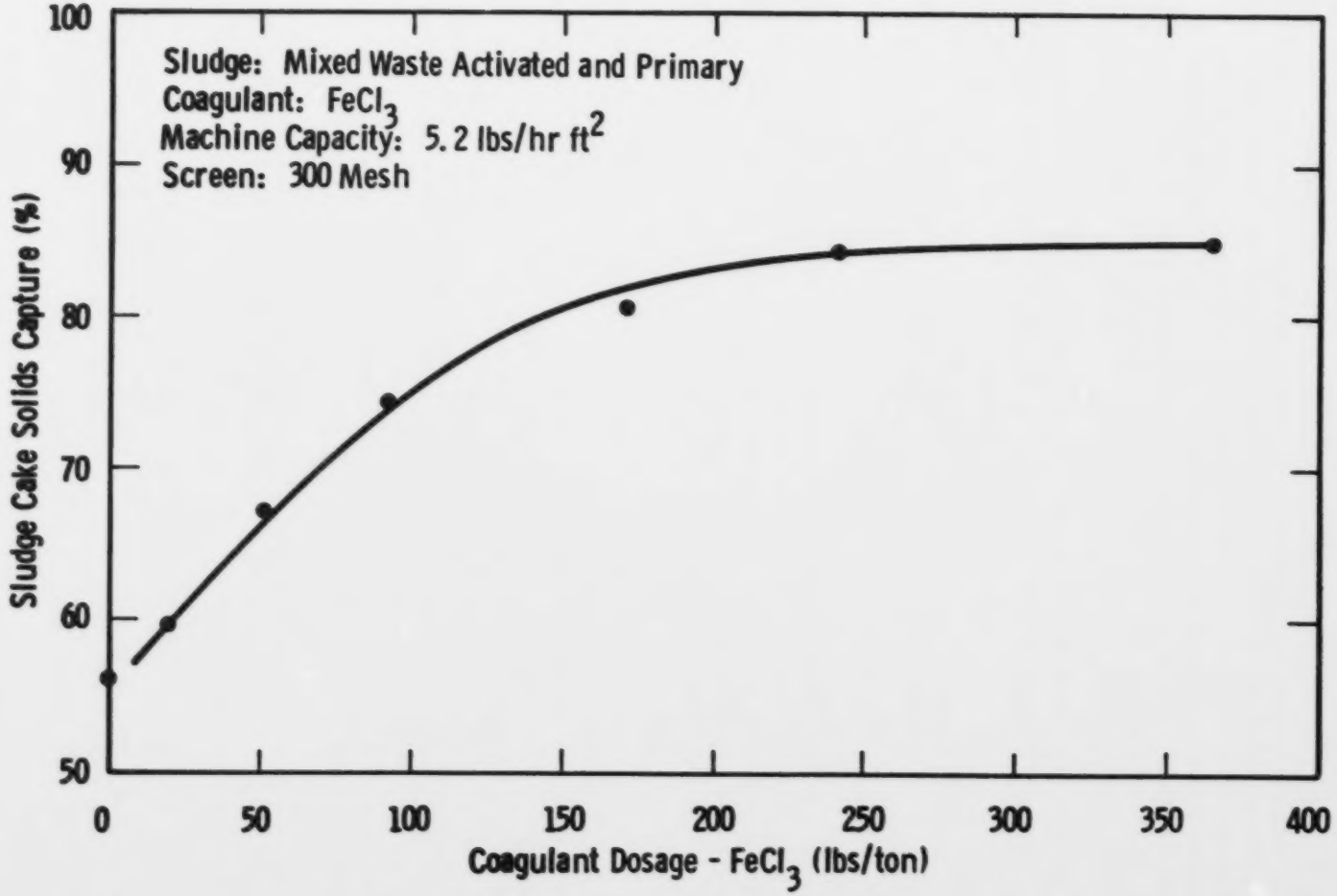

Fig. 35– Capillary dewatering - sludge cake solids capture
(Kgs/m^2 =).205 lbs/ft^2, Kgs/ton(m) = 2.0 lbs/ton)

problems encountered in pumping the sludge to maintain the uniform and thin sludge layers required for the higher machine capacity operation. The sludge cake would detach cleanly (preferentially adhere to the compression roller) even over a relatively wide range of compression force settings. With this sludge, the machine could be run unattended for relatively long periods of time (several hours). The ease of operation with the activated sludge is attributed to the sludge's homogeneity. The mixed primary sludge exhibited a similar homogeneity but was heavier (higher solids content). This sludge has a strong anaerobic odor making it unpleasant to work with.

With the anaerobically digested sludge, pump clogging was frequently encountered because of hair and large solids. This problem was circumvented by changing pumps.

With the heavier sludges i.e., both the mixed and digested sludges, the compression roller section operation (cake detachment) appeared more sensitive to change in coagulant dosage, coagulant type and roller force. These are qualitative observations that need additional investigation.

The most serious mechanical problem encountered in operating the pilot unit was maintaining the integrity of the screen belt for extended periods. During the early part of the program, frequent screen failures were encountered (after only 2 or 3 weeks operation). The screen was observed to tear at the seam and near the edges. These screen failures were not catastrophic but gradual. The failure at the seam was attributed to the method of fastening the screen together. It had been sewn. Sewing the screen actually put a non-uniform and point loading on the screen fibers. This mode of failure was finally corrected by subsequently bonding the two ends of the screen together. This proved to be an easy and effective method of screen attachment. The tears at the edge of the screen were eliminated by edging the screen (doubling over the screen to put a 1/4 inch edge along both sides) and eliminating screen contact with sharp metal edges on the unit. For example, the screen guides were removed and a teflon edging was put on the underside of the feed tray. These changes appeared to signifianntly improve the screen integrity during the remaining portion of the test program (about 3 months). It is not known whether the fine mesh screens used in this pilot study would be acceptable in large scale field systems. Heavier (large fiber diameters) screens may be needed for these systems.

Only one porous belt was used during the course of this investigation. There were no operating problems encountered with this belt, and the belt, in fact, still appears in excellent condition.

Several minor machine operating problems were encountered and solved during the course of this study. This included some spray water replumbing to prevent water run-back (into the belt) and retracking the screen belt to take maximum advantage of the large belt area. The reader is referred to Appendix B, Tables 1 through 4. Included in the tables are some general comments that reflect some of the operating problems encountered.

SECTION V

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SECTION VI

APPENDIX A - Error Analysis

The data from any experiment can only be interpreted within the limits of the accuracy and reliability of the measurements. These limits are difficult and often impossible to ascertain in single sample experiments. Nevertheless, it is necessary for the experimenter to attempt to describe the uncertainties in the data in order to add credence to the results. Such an analysis would first be extremely helpful in selecting the apparatus best suited for the experiment, and secondly, give the experimenter a basis for evaluating his data.

An analysis has been conducted to describe the uncertainties in the data reported herein. The calculations are based on the equations presented by Kline and McClintock,[6] who show that the uncertainty interval W_r in some function R of n independent variables V_i is given by

$$W_r = \left[\left(\frac{\partial R}{\partial V_1} W_1\right)^2 + \left(\frac{\partial R}{\partial V_2} W_2\right)^2 + \ldots + \left(\frac{\partial R}{\partial V_n} W_n\right)^2\right]^{1/2}$$

where W_i is the uncertainty interval in the variable V_i. In developing the above equation, it was assumed that the same odds exist for each of the variable intervals and for the result i.e., if the confidence intervals of the W_i variables are 90 percent, then the confidence interval on W_r will also be 90 percent. Using this equation, the uncertainty in the variables can be estimated. The basic measured quantities and their respective uncertainty intervals are summarized in Table A.1. The confidence intervals in the variables were arbitrarily set at 90 percent. The calculations for the error in the derived quantities are summarized below.

Table A-1. EXPECTED UNCERTAINTY IN MEASURED VARIABLES

Quantity	Typical value and confidence interval
1. Belt active length	50 ± 1.0 inch (cm = .39 in)
2. Belt active width	10.5 ± 0.25 inch
3. Sludge total suspended solids	
a. Activated	19,000 ± 100 mg/ℓ
b. Mixed-activated primary	40,000 ± 400 mg/ℓ
c. Anaerobically digested	45,000 ± 450 mg/ℓ
4. Sludge sample weights (gram balance)	
a. Beaker wt.	173 ± 0.1 gm
b. Beaker wt. + wet solids	360 ± 0.1 gm

Table A-1 (continued). EXPECTED UNCERTAINTY IN MEASURED VARIABLES

Quantity	Typical value and confidence interval
c. Beaker wt. + dry solids	200 ± 0.1 gm
5. Time measurements (stop watch)	
a. Solids capture measurement	60 ± 1.0 sec.
b. Sludge feed measurement (low)	15 ± 0.25 sec.
c. Sludge feed measurement (high)	10 ± 0.25 sec.
6. Sludge volume measurement (graduate cylin.)	
a. Activated sludge (low feed rates)	600 ± 10 mℓ
b. Activated sludge (high feed rates)	1000 ± 25 mℓ
c. Mixed-primary-activated	1000 ± 50 mℓ
d. Anaerobically digested	1000 ± 50 mℓ
7. Chemical feed rate	10 ± 1 mℓ/min

a. Experimental Uncertainty in Sludge Flow Rate (W.A.S.)

F.R. = Flow Rate - Sludge Volume/time = S.V./t

From Equation A-1, the uncertainty in sludge flow rate becomes;

$$\frac{W_{F.R.}}{F.R.} = \left[\left(\frac{W_{S.V}}{S.V}\right)^2 + \left(\frac{W_t}{t}\right)^2\right]^{1/2} \qquad (A\text{-}2)$$

Now, from Table A-1,

$$\frac{W_{S.V}}{S.V.} = \frac{\pm 10}{600} \pm 1.7\%$$

$$\frac{W_t}{t} = \frac{\pm 1}{60} = \pm 1.7\%$$

Therefore, from Equation (A-2),

$$\frac{W_{F.R.}}{F.R.} = \pm 2.4\% \quad \text{(low sludge feed rates)}$$

Similarly, for the high feed rates,

$$\frac{W_{F.R.}}{F.R.} = \pm 3.5\%$$

b. Experimental Uncertainty in Machine Capacity (W.A.S.)

$$\text{Machine Capacity} = \frac{\text{Sludge Solids Wt x Sludge Feed Rate x Conversion Factors}}{\text{Belt Area}}$$

$$\text{or } M.C. = \frac{S.W. \times F.R.}{B.A.}$$

Thus, the uncertainty in machine capacity is;

$$\frac{W_{M.C.}}{M.C.} = \left[\left(\frac{W_{S.W.}}{S.W.}\right)^2 + \left(\frac{W_{F.R.}}{F.R.}\right)^2 = \left(\frac{W_{B.A.}}{B.A.}\right)^2\right]^{1/2}$$

The uncertainty in belt area, $\frac{W_{B.A.}}{B.A.}$, is given by; B.A. = length x width) thus, from Table A-1,

$$\frac{W_{B.A.}}{B.A.} = \left[\left(\frac{1.0}{50}\right)^2 + \left(\frac{.25}{10.5}\right)^2\right]^{1/2} = \pm 3.3\%$$

Thus; from Table A-1 and above, (low capacities);

$$\frac{W_{M.C.}}{M.C.} = [(.005)^2 + (.024)^2 + (.033)^2]^{1/2} = \pm 4.1\%$$

Similarly, for the higher capacities,

$$\frac{W_{M.C.}}{M.C.} = \pm 4.8\%$$

c. Experimental Uncertainty in Cake Solids Capture (W.A.S.)

$$\text{Solids Capture} = \text{S.C.} = \frac{\text{Dry Solids From Roller}}{\text{Dry Solids From Feed}} = \frac{\text{D.S.R.}}{\text{D.S.F.}}$$

Therefore,

$$\frac{W_{S.C.}}{S.C.} = \left[\left(\frac{W_{DSR}}{DSR}\right)^2 + \left(\frac{W_{DSF}}{DSF}\right)^2\right]^{1/2} \qquad \text{(A-3)}$$

The uncertainty in the measurement in the dry cake solids from the compression roller is a result of three factors:

1. weighings $\pm 0.5\%$
2. sampling time $\pm 1.7\%$ (60 second sample with a ± 1.0 second accuracy)
3. edge losses $\pm 2\%$ (estimate)

On this basis, then, the uncertainty in the dry cake solids wt. from the compression roller is,

$$\frac{W_{DSR}}{DSR} = \begin{matrix} -2.2\% \\ +4.2\% \end{matrix}$$

The uncertainty in feed dry solids wt. is basically in measurement of this sludge feed rate.

$$\frac{W_{DSF}}{DSF} = \pm 2.4\%$$

Thus, from Equation (A-3), the uncertainty in cake solids capture is;

$$\frac{W_{S.C.}}{S.C.} = \left[\frac{(.022)^2}{(.042)^2} + (.024)^2\right]^{1/2}$$

$$\frac{W_{S.C.}}{S.C.} = \begin{matrix} +4.9\% \\ -3.2\% \end{matrix} \text{ (low feed rates)}$$

Similarly,

$$\frac{W_{S.C.}}{S.C.} = \begin{matrix} +5.3\% \\ -4.1\% \end{matrix} \text{ (high feed rates)}$$

Similar calculation follows for the mixed activated-primary sludge and for the anaerobically digested sludge using the uncertainties given in Table A-1. The results of the calculations are given in Table 3 of the text.

SECTION VII

APPENDIX B - A Chronological Summary Listing of Test Data--Pilot Test Unit

A summary of test data from the pilot unit is given in Tables 1B through 5B. The data is arranged in chronological order. Included in each table are (1) Run number which merely corresponds to the date of testing i.e., month and day (522 - May 22) and (2) Type of sludge - ACT - waste activated sludge, DIGST - anaerobically digested sludge and MIXPRIM - mixed primary activated sludges. The remaining columns are self explanatory.

Table 1B summarizes data obtained during the initial start-up and system shakedown series. During this time, most of the machine operating problems were solved and improved experimental methods for obtaining solids recovery values were developed. The data is limited to basic machine performance on activated sludge using one screen type.

Table 2B shows data that reflects a continuation of developing base line system performance. Methods for obtaining solids recovery data were incorporated during this time along with attention to measuring roller compression forces. Initial data on the digested and mixed primary sludges was also obtained.

Tables 3B and 4B summarize data obtained with activated sludge during that portion of the program that involved developing a more basic understanding of various system parameter interactions. This included varying coagulant dosage rates, belt speeds, sludge feed rates, screen type, and roller compression forces. These sets of data constitute the most reliable and informative compilation of tests conducted on waste activated sludge during this program.

Table 5B summarizes data taken in the anaerobically digested and mixed primary sludges.

Table 1-8 Pilot Test Unit - Summary of Data From May 22 through Aug. 10, 1972 - System Installation and Shakedown

Run	Sludge	Coagulant Type	Coagulant (lbs/ton)	Cake Solids (%)	Comp. Force (lbs/in)	Solids Loading (lbs/ft^2)	Machine Capacity (lbs/hr ft^2)	Solids Recovery (%)	Run Time (hrs)	Screen Type (Mesh)	Comments
522	Act	None	0	13.2	-	0.0097	2.32	-	3.0	200	Shakedown - comp. force not measured
524	Act	C-31	17	13.5	-	0.0135	2.04	-	3.0	200	
602	Act	$FeCl_3$	103	16.3	-	0.0121	2.18	-	2.5	200	
606	Act	C-31	5	16.2	-	0.0084	2.52	-	4.0	200	Belt tore at seam--resewn
607	Act	C-31	5	15.9	-	0.0083	2.40	-	4.0	200	
608	Act	C-31	7	15.7	-	0.0091	2.72	-	4.0	200	
609	Act	C-31	14	15.5	-	0.0063	1.89	-	3.5	200	
612	Act	C-31	1.3	16.4	-	0.0098	2.93	-	4.5	200	
614	Act	C-31	8	15.8	-	0.0110	1.33	-	4.5	200	
627	Act	$FeCl_3$	28	17.2	-	0.0095	2.83	-	4.0	200	
628	Act	$FeCl_3$	27	18.4	-	0.0093	2.78	-	2.5	200	Changed compression roller - machined stainless steel.
713	Act	$FeCl_3$	300	15.4	-	0.0066	1.98	-	3.0	200	Chem. feed pump not functioning.
718-A	Act	$FeCl_3$	95	17.8	-	0.0088	2.65	-	4.0	200	Screen repaired prior to run.
718	Act	$FeCl_3$	140	18.1	-	0.0088	2.65		3.5	200	Repaired feed pump.
719-A	Act	$FeCl_3$	52	17.3	-	0.0081	2.41	-	3.0	200	
719	Act	$FeCl_3$	270	20.3	-	0.0071	2.13	-	4.0	200	Comp. roller hanging up.
720	Act	$FeCl_3$	230	17.4	-	0.0071	2.20	-	4.0	200	
720-A	Act	$FeCl_3$	21	18.9	-	0.0082	2.46	*	4.0	200	Screen wash water spilling into belt effluent stream - All prior solids recovery data invalid. Screen tore.
726	Act	None	0	17.1	-	0.0078	2.44	-	3.5	*	Changed screens - new one 200. Bonding screen together.
728	Act	None	0	17.0	-	0.0068	2.12	-	4.0	200	
731	Act	None	0	18.0	-	0.0081	2.53	-	4.5	200	Belt dirty--wash w/ soap & water.
801	Act	None	0	16.2	-	0.0081	2.62	-	4.0	200	
802	Act	None	0	16.6	-	0.0077	2.30	-	4.5	200	
803	Act	None	0	16.8	-	0.0077	2.29	-	2.0	200	
808	Act	None	0	16.5	-	0.0080	2.60	-	4.0	200	Comp. roller stalling
809	Act	C-31	5	17.5	-	0.0070	2.50	-	3.0	200	
810	Act	C-31	5	16.6	-	0.0070	2.50	-	2.5	200	Changed position of comp. roller. Retracked belt.

(Kgs/ton(m) = 2.0 lbs/ton, Kg/m = 0.056 lbs/in., Kgs/m^2 = 0.205 lbs/ft^2)

Table 2-B Pilot Test Unit - Summary of Data From Aug. 16 through Oct. 4, 1972 - Base Line System Performance

Run	Sludge	Coagulant Type	Coagulant (lbs/ton)	Cake Solids (%)	Comp. Force (lbs/in)	Solids Loading (lbs/ft^2)	Machine Capacity (lbs/hr ft^2)	Solids Recovery (%)	Run Time (hrs)	Screen Type (Mesh)	Comments
816	Act	C-31	5	17.6	18.5	0.0079	1.89	70.3	2.5	200	Solids recovery data obtained -- comp. force recorded.
817	Act	C-31	4	17.9	18.5	0.0088	2.10	66.2	2.5	200	
818	Act	C-31	3	17.8	16.4	0.0078	1.87	74.2	4.0	*	Holes noticed in screen. New screen 200.
821	Act	C-31	7	18.6	18.5	0.0081	1.95	68.1	4.0	200	
823	Act	C-31	10	17.6	16.4	0.0078	1.89	74.8	4.0	200	Chem. feed pump malfunction -- comp. roller stalling.
824	Act	C-31	19	19.8	20.4	0.0082	1.98	84.8	4.0	200	Comp. roller stalling
825	Act	C-31	9	18.3	18.5	0.0086	2.06	67.5	4.0	200	Comp. roller again stalling.
828	Act	C-31	2	18.7	20.4	0.0078	1.88	73.1	4.0	200	Replaced chem. feed pump.
829	Act	C-31	0.5	19.4	20.4	0.0077	1.86	62.8	5.0	200	
830-A	Act	$FeCl_3$	190	19.3	20.4	0.0079	1.89	80.8	1.0	200	
830-B	Act	$FeCl_3$	95	20.0	20.4	0.0079	1.89	75.2	1.0	200	
830-C	Act	$FeCl_3$	48	19.1	20.4	0.0079	1.89	67.8	1.0	200	
830-D	Act	$FeCl_3$	19	20.2	20.4	0.0079	1.89	75.2	1.0	200	
830-E	Act	$FeCl_3$	9	20.3	20.4	0.0079	1.89	57.3	1.0	*	Changed screen after test runs-200.
908	Digst	$FeCl_3$	9	20.0	16.4	0.0135	3.21	66.0	2.0	200	Changed over to digested sludge -- using clips to fasten belt - pump clogged.
911	Digst	ST-260	2	19.9	-	0.0165	3.96	75.3	3.5	200	Comp. roller stalling - poor cake pick up.
913	Act	None	0	18.9	17.4	0.0085	2.05	59.0	1.0	200	Changed back to activated sludge.
913-A	Act	C-31	9	18.8	16.4	0.0085	2.05	87.8	1.0	200	
915	Act	C-31	5	-	-	0.0071	1.70	84.0	0.5	200	Cake solids not measured.
915-A	Act	C-31	6	-	-	0.0071	1.70	89.0	0.5	200	Comp. roller stalling.
918	Act	C-31	50	18.6	20.4	0.0047	0.88	90.0	1.5	200	Sludge diluted by heavy rainfall.
919	Act	C-31	34	19.2	20.4	0.0045	1.07	84.0	2.0	200	Sludge diluted by heavy rainfall.
920-25	Digst	ST-260	2	21.2	-	0.0011	3.10	65.6	8.0	200	Changed to digested sludge -- waiting for normal RAS conditions.
927	Act	C-31	26	19.7	20.4	0.0061	1.48	92.5	3.0	200	Changed back to activated sludge.
1003	Mix-Prim		-	-	-	-	-	-	-	200	Tried mixed primary - no data
1004	Mix-Prim	C-31	5	20.8	-	0.0084	2.32	-	4.0	*	Screen tore on cleaning -- replaced with 300 mesh.

Table 3-B Pilot Test Unit - Summary of Data From Oct. 11 through Nov. 16, 1972 - Initial Study of Machine Parameters on Waste Activated Sludge.

Run	Sludge	Coagulant Type	Coagulant (lbs/ton)	Cake Solids (%)	Comp. Force (lbs/in)	Solids Loading (lbs/ft^2)	Machine Capacity (lbs/hr ft^2)	Solids Recovery (%)	Run Time (hrs)	Screen Type (Mesh)	Comments
1011	Act	C-31	2.8	18.2	18.5	0.0071	1.98	88.0	4.0	300	Now using 300 mesh screen.
1012	Act	C-31	4.5	18.0	18.5	0.0069	2.05	82.0	4.0	300	
1012-A	Act	C-31	6.7	17.6	18.5	0.0069	2.05	83.0	1.0	300	
1016	Act	C-31	-	-	-	-	-	-	3.5	300	Lost data.
1017-A	Act	C-31	4.5	-	-	0.0067	1.85	-	1.0	300	Capillary profile study.
1017-B	Act	C-31	2.0	18.2	20.4	0.0067	1.85	83.0	1.0	300	Capillary profile study.
1017-C	Act	C-31	3.9	18.7	20.4	0.0067	1.85	90.0	1.0	300	Capillary profile study.
1018	Act	C-31	4.5	-	-	0.0213	-	-	1.0	300	Capillary profile study. Screen developing holes.
1027	Act	None	0	18.0	20.4	0.0057	1.36	74.0	1.5	300	Screen tore. Changed screens for next run.
1031	Act	C-31	94.0	19.1	16.4	0.0054	1.29	99.5	2.0	200*	New screen.
1031-A	Act	C-31	70.0	18.3	16.4	0.0054	1.29	99.1	1.5	300	
1102	Act	C-31	18.7	17.0	20.6	0.0042	3.02	91.1	2.0	300	
1106-A	Act	C-31	29.0	17.7	18.5	0.0043	3.06	88.0	1.0	300	Problem w/sludge cake detachment.
1106-B	Act	C-31	44.5	17.7	18.5	0.0043	3.06	85.5	1.0	300	
1106-C	Act	C-31	62.5	16.7	18.5	0.0043	3.06	91.0	1.0	300	
1107-A	Act	None	0	16.0	16.4	0.0031	2.79	59.0	1.0	300	
1107-B	Act	C-31	3.0	16.5	16.4	0.0031	2.79	75.9	1.5	300	
1107-C	Act	C-31	11.6	16.7	16.4	0.0031	2.79	94.0	0.5	300	
1110-A	Act	C-31	5.4	15.5	18.5	0.0028	3.54	77.0	2.5	300	Capillary profile study.
1110-B	Act	C-31	13.4	16.5	18.5	0.0028	3.54	84.0	2.5	300	Capillary profile study.
1113-A	Act	None	0	17.3	16.4	0.0075	1.81	69.4	1.0	300	
1113-B	Act	C-31	3.0	17.3	16.4	0.0075	1.81	68.0	1.0	300	
1114-A	Act	C-31	5.1	17.2	16.4	0.0067	1.73	75.0	1.0	300	
1114-B	Act	C-31	7.6	17.0	16.4	0.0067	1.73	85.0	1.0	300	
1116-A	Act	None	0	16.0	16.4	0.0042	3.02	51.1	1.0	300	
1116-B	Act	C-31	3.2	16.6	16.4	0.0042	3.02	60.3	1.0	*	Screen tore. Changed screens after run.

Table 4-B Pilot Test Unit - Summary of Data From Dec. 1 through Jan. 1, 1973 - Continue Study of Machine Performance on Waste Activated Sludge.

Run	Sludge	Coagulant Type	Coagulant (lbs/ton)	Cake Solids (%)	Comp. Force (lbs/in)	Solids Loading (lbs/hr ft^2)	Machine Capacity (lbs/hr ft^2)	Solids Recovery (%)	Run Time (hrs)	Screen Type (Mesh)	Comments
1201-A	Act	None	0	14.5	12.4	0.0044	4.6	53.0	1.0	300	Using new screen. Running belt at high speeds.
1201-B	Act	C-31	8.2	14.1	12.4	0.0044	4.6	80.0	1.0	300	Capillary profile study.
1201-C	Act	C-31	5.6	14.5	12.4	0.0044	4.6	75.0	1.0	300	Capillary profile study.
1201-?	Act	C-31	2.6	15.5	12.4	0.0044	4.6	64.0	1.0	300	Capillary profile study.
1204-A	Act	C-31	18.5	14.5	12.4	0.0045	4.6	92.2	1.0	300	Capillary profile study.
1204-B	Act	C-31	11.7	16.1	12.4	0.0045	4.6	68.0	1.0	300	Shaft on drive roller broke.
1218-A	Act	C-31	55.0	15.5	12.4	0.0043	4.5	87.0	1.0	300*	Question solids recovery number.
1218-B	Act	C-31	41.0	15.8	12.4	0.0043	4.5	87.0	1.5	300	New screen - same mesh
1218-C	Act	C-31	12.0	-	-	0.0043	4.5	85.0	1.5	300	Capillary profile study.
1219-A	Act	$FeCl_3$	57.6	13.1	12.4	0.0042	4.3	77.0	1.5	300	Capillary profile study.
1219-B	Act	$FeCl_3$	34.6	15.0	12.4	0.0042	4.3	65.0	1.5	300	Capillary profile study.
1219-C	Act	$FeCl_3$	23.0	13.7	12.4	0.0042	4.3	60.5	1.5	300	Capillary profile study.
1220-A	Act	$FeCl_3$	542.0	16.3	12.4	0.0042	4.3	93.0	1.7	300	Capillary profile study.
1220-B	Act	$FeCl_3$	401.0	18.3	12.4	0.0042	4.3	93.5	2.2	300	Capillary profile study.
1220-C	Act	$FeCl_3$	293.0	14.3	12.4	0.0042	4.3	94.0	2.1	300	Capillary profile study.
109 (73)	Act	$FeCl_3$	209.0	15.0	12.4	0.0042	4.3	90.5	1.5	325*	Screen tore-replaced w/325 mesh.
117 (73)	Act	$FeCl_3$	127.0	15.2	12.4	0.0051	5.3	90.8	1.6	300	Capillary profile study.

Table 5-B Pilot Test Unit - Summary of Data From Jan. 26 through Feb. 14, 1973 - Continue of Study of Machine Performance with Digested and Mixed Primary Sludges.

Run	Sludge	Coagulant		Cake Solids (%)	Comp. Force (lbs/in)	Solids Loading (lbs/ft^2)	Machine Capacity (lbs/hr ft^2)	Solids Recovery (%)	Run Time (hrs)	Screen Type (Mesh)	Comments
		Type	(lbs/ton)								
126 (73)	Digst	None	0	13.4	12.4	0.0056	5.74	55.3	2.0	325*	New screen.
129-A(73)	Digst	$FeCl_3$	43	15.3	12.4	0.0060	6.18	65.2	1.5	325	
129-B	Digst	$FeCl_3$	73	15.9	12.4	0.0060	6.18	71.7	1.5	325	
129-C	Digst	$FeCl_3$	14.2	14.8	12.4	0.0060	6.18	61.3	1.5	325	
130-A(73)	Digst	$FeCl_3$	170	15.8	12.4	0.0050	5.17	81.0	2.0	325	
130-B	Digst	$FeCl_3$	242	18.4	12.4	0.0050	5.17	88.4	2.0	325	
131-A(73)	Digst	$FeCl_3$	345	16.4	12.4	0.0053	5.45	92.4	2.0	325	
131-B	Digst	$FeCl_3$	460	16.0	12.4	0.0053	5.45	97.3	2.0	325	
213-A(73)	Mix-Prim	None	0	14.0	12.4	0.0056	5.05	56.8	1.5	325	
213-B	Mix-Prim	$FeCl_3$	17.5	14.5	12.4	0.0056	5.05	59.5	1.5	325	
213-C	Mix-Prim	$FeCl_3$	52.6	14.7	12.4	0.0056	5.05	67.0	0.5	325	
213-D	Mix-Prim	$FeCl_3$	89.4	15.0	12.4	0.0056	5.05	74.6	1.5	325	
214-A(73)	Mix-Prim	$FeCl_3$	172	15.0	12.4	0.0060	5.05	80.5	1.5	325	
214-B	Mix-Prim	$FeCl_3$	246	15.0	12.4	0.0060	5.42	84.3	1.5	325	
214-C	Mix-Prim	$FeCl_3$	369	15.3	12.4	0.0060	5.42	84.9	2.0	325	

SECTION VIII

APPENDIX C - Economics of Capillary Dewatering on Waste Activated Sludge

Any product or process which is to be used by customers and for which there are substitute products available must be economically justifiable in order to be useful. To this end, an estimate of the cost of dewatering waste activated sludge by the capillary suction method must ultimately be considered.

The task of providing a detailed cost prediction for this process under all possible operating conditions is extremely difficult because of the number of parameters of choice which the customer can vary. Since machine capacity and performance is the ultimate design parameter which will set the equipment size, the foremost question is under what conditions will the capacity be measured. The parameters of choice are independent of each other over small ranges but interdependent over gross ranges. These include:

- Exit solids concentration
- Solids capture percentage
- Coagulant type (inorganic or polyelectrolyte)
- Feed solids concentration

In addition, dependent variables such as belt contact times and solids loading rates have an effect on capacity also. Earlier in this paper, curves were presented showing the capacity as a function of polymer dosage and solids loading rate. If similar curves were available for feed solids concentration and solids capture as functions of the other parameters, then an economic analysis could be made that would be very inclusive.

To eliminate these problems and still provide a justifiable economic analysis, cost estimates were made for three selected operating conditions which were demonstrated during the course of the program. The calculations assume a constant machine size and an activated sludge of 2% as feed to facilitate run to run comparisons.

Using these assumptions as a basis, sewage plant size will be a variable in the comparisons. Extension of the assumptions to larger scale plants such as 10 to 100 mgd would require substantiating the data at plant scale.

Costs were developed (Table C-1) at two levels of machine capacity i.e., 2.0 and 4.5 lbs/hr ft^2 (10 and 22 Kg/hr m^2) and for two coagulants at the higher capacity; ferric chloride and a cationic polyelectrolyte. The only costs considered are:

- machine capital
- maintenance and repair
- electrical
- coagulant
- labor

Costs such as building, land, feed systems, removal systems, and ultimate disposal were not considered due to the wide variations possible in these systems and the fact that many of these facilities are available in existing plants. The costs shown in Table C-1 are for the dewatering function only.

There are several interesting items to note in these costs. As usual, the labor costs are a significant portion (50% or more) of the cost of dewatering the sludge. The 1/2 man day estimate may be high since once the unit is started, it should run automatically. Because of the preparation and clean up time, however, a half man day is probably realistic.

The coagulant costs for both ferric chloride and polyelectrolyte are similar with a higher cost for the polymer. The ferric seemed to perform better but has corrosion problems. A cost of $3/ton ($3.30/metric ton) is not unreasonable for this type of treatment however.

The power costs in this system are of note because they are so low. At $130/year, they are only 3% to 5% of comparable costs for centrifuges or vacuum filters. With the cost of power increasing very rapidly, and present emphasis on energy conservation, the low power cost makes this method attractive.

Decreasing machine capacity from 4.5 pounds/hr ft^2 (22 Kg/hr m^2) to 2 lbs/hr ft^2 (10 Kg/hr m^2) essentially doubles the total cost. The machine capacity markedly affects the system economics. The exit dry solids in the lower capacity case are significantly higher than the high capacity case which will offset some of the cost. These figures point out the trade off capability of the system.

The costs detailed here are competitive with existing systems such as vacuum drum filters, pressure filters, and centrifuges. In fact, on waste activated sludge, achievement of 15% to 17% solids is extremely difficult with other systems.

Table 1-C

Cost Estimates For Capillary Dewatering

Basis for Cost Calculation

Assumptions

1. Capillary device capital cost is $300 per active square foot of capacity and is linear with capacity.

2. Machine size is 110 ft^2 of active areas.

3. Operation schedule is 8 hour/day, 7 days/week, 360 days/year.

4. Machine performance as in run 1218A data sheet.

   Performance data: 55 lbs/ton ferric chloride as coagulant
   4.5 lbs/hr ft^2 machine capacity
   87% solids capture
   15.5% exit solids cake
   Waste activated sludge feed of ∿2% solids

5. No costs for overhead, peripheral feed equipment, or building.

Annual Cost Calculations

1. Capital

   110 ft^2 machine at $300/$ft^2$ = $33,000

   Amortization over 20 years at 6% $2,877

   (m^2 = .093 ft^2, Kgs/ton(m) = 2.0 lbs/ton, Kgs/m^2 = 0.205 lbs/ft^2, Kg = 2.2 lbs, ton(m) = 1.1 ton, (HP-M = .986 HP)

2. Coagulant cost at 5¢/lb ferric chloride

$$\frac{4.5 \text{ lbs}}{\text{hr ft}^2} \times 110 \text{ ft}^2 \times \frac{8 \text{ hours}}{\text{day}} \times \frac{360 \text{ days}}{\text{year}} \times \frac{1 \text{ ton}}{2000 \text{ lbs}} = 712.8 \text{ tons}$$

   (Approximately 4 mgd plant (16 m^3/day))

$$712.8 \text{ tons} \times \frac{50 \text{ lbs}}{\text{ton}} \times \frac{\$.05}{\text{lb}} \qquad \$1,782$$

3. Power: assume 5 hp 230 v 30 motor

   230v x 13a ∿ 3Kw

$$3 \text{ Kw} \times \frac{\$.015}{\text{Kw-hr}} \times \frac{8 \text{ hrs}}{\text{day}} \times \frac{360 \text{ day}}{\text{year}} \qquad \$ \ 130$$

Table 1-C (continued)

4. Maintenance @ 5.5% of capital/year

   $33,000 x .055 — $1,815

5. Labor 1/2 man day/day at $5.00/man hour

   $\frac{4 \text{ man hours}}{\text{day}} \times \frac{\$5}{\text{man hour}} \times 360 \text{ days}$ — 7,200

Total annual cost for above items — $13,804

Cost/ton = $13804/712.8 — $19.36/T

Run 1201B same conditions but polyelectrolyte

Performance data: 8.2 lbs/ton C-31 polyelectrolyte as coagulant
4.6 lbs/hr ft^2 machine capacity
80% solids capture
14.1% exit solids cake
Waste activated sludge feed of ∿2% solids

1. Capital — $2,877

2. Coagulant cost at 40¢/lb C-31

   $\frac{4.6 \text{ lbs}}{\text{hr ft}^2} \times 110 \text{ ft}^2 \times \frac{8 \text{ hrs}}{\text{day}} \times \frac{360 \text{ days}}{\text{year}} \times \frac{1 \text{ ton}}{2000 \text{ lbs}} = 729 \text{ tons}$

   (approximately 4 mgd plant (16 m^3/day))

   $729 \text{ tons} \times \frac{8.2 \text{ lbs}}{\text{ton}} \times \frac{\$.40}{\text{lb}} =$ — $2,391

3. Power — $ 130

4. Maintenance — $1,815

5. Labor — $7,200

$14,413

Cost/ton = $14,413/729 — $19.77/ton

Run 1012A

Performance data: 6.7 lbs/ton C-31 polyelectrolyte coagulant
2.05 lbs/hr ft^2 machine capacity
83% solids capture
17.6% exit solids cake
Waste activated sludge feed at ∿2% solids

Table 1-C (continued)

1. Capital — $2,877

2. Coagulant cost at 40¢/lb C-31

$$\frac{2.05 \text{ lbs}}{\text{hr ft}^2} \times 110 \text{ ft}^2 \times \frac{8 \text{ hrs}}{\text{day}} \times \frac{360 \text{ days}}{\text{year}} \times \frac{1 \text{ ton}}{2000 \text{ lbs}} = 325 \text{ tons}$$

(approximately 2 mgd plant (8 m^3/day))

$$325 \text{ tons} \times \frac{6.7 \text{ lbs}}{\text{ton}} \times \frac{\$.40}{\text{lb}}$$ — $ 870

3. Power — $ 130

4. Maintenance — $1,815

5. Labor — $7,200

$12,892

Cost/ton = 12892/325 — $39.67/ton